THE EVALUATION OF THE CORRELATION BETWEEN ABRASION RESISTANCE AND WEAVEABILITY OF SIZED WARP YARNS

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OF SIZED WARP YARNS

A THESIS

Presented to

the Faculty of the Graduate Division

Georgia Institute of Technology

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Textile Engineering

By

George Blake Anderson

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Thesis

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THE EVALUATION OF THE CORRELATION BETWEEN ABRASION RESISTANCE AND WEAVEABILITY OF SIZED WARP YARNS

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ABSTRACT

In the weaving of yarn into cloth it is necessary to coat each warp yarn with a film of size to reduce the frictional forces between the yarn and loom parts to a minimum. There is no generally accepted method of evaluating the effects of friction on the weaving qualities of warp yarns in the laboratory. The tensile strength and elongation are not good measures by which to evaluate the weaving qualities; however, it has been proposed that the abrasion resistance of the yarn would be a good method for evaluating the weaving qualities of a sized warp yarn, since a good correlation exists between the weaveability and the abrasion resistance of the yarn.

In the experimental portion of this study six different sized warp yarns from six different mills were tested for tensile strength, elongation and abrasion resistance. By using data obtained from the respective mills regarding the weaveability of the yarns and the physical characteristics of the yarn (tensile strength, elongation and abrasion resistance) a coefficient of correlation was calculated for the relationship between the yarn characteristics and weaveability.

It was determined that a good correlation existed for the relationship between the tensile strength and weaveability; also, that a good relationship existed between the abrasion resistance and the weaveability. The experiments brought out that a poor relationship existed between the elongation and weaveability.

It is the author's conclusion that although abrasion resistance could conceivably be a good method of evaluating a warp size, more work

would be necessary to develop a method that would predict the weave-ability of a warp yarn, *per se*.

CHAPTER I

INTRODUCTION

It is well known that in order to insure optimum weaveability under a given set of weaving conditions single warp yarns must be coated individually with a size compound usually containing starch, gum, softeners, penetrants and preservatives. The starch produces a film on the yarn which binds the fibers on the surface of the yarn to the body of the yarn; this results in a smoother and stronger yarn which can be woven more efficiently. The gums are used in the size to toughen the starch film and to increase the resistance to abrasion which is encountered during the weaving process. Softeners are used to make the starch film pliable and flexible and also to counteract the resultant decrease in elasticity between the unsized and sized yarn. The penetrants are used to increase the ease of application and the preservatives are compounds to protect the yarn from mildew. The process of applying this size compound is known as slashing. Castle and Dawson (1) sum up the problem of sizing as follows:

> The perfect sizing treatment has yet to appear and so far there is little evidence of a determined effort to find it. It is unfortunate that this should be so, for although sizing is a palliative and not a cure for bad yarn, it should be more generally realized that the loom efficiencies of bad warps can be increased by as much as 15 per cent by modifications of treatments previously considered suitable.
>
> A perfect sizing treatment should cover the yarn uniformly with a smooth, thin, strong and flexible film of excellent binding properties, should be very resistant to abrasion in the loom, and preferably should have sufficient surface

> lubrication to reduce friction against loom parts to a minimum. That is the ideal, but to come within measurable distance of realizing it means exploring such fields as synthetic organic chemicals and double bath processing. This in turn will involve in all probability, revision of generally held opinions on sizing costs, and reconsidering them in relation to increases in loom efficiency and not as separate items.
>
> A very real snag, of course, in the development of new sizes is the problem of evaluation. Laboratory methods are useful, but at most they can serve only to eliminate obvious failures. The real test is in the loom. Here again the many variables that enter into a systematic assessment of loom efficiency complicate the evaluation of a trial sizing and are apt to act as a deterrent. Development work has to be systematic and the comparatively slow rate of progress enforced by work conditions makes a heavy demand on the patience of the weaver whose out look is governed by production needs. These reasons are no doubt largely responsible for the slow development of sizing, but once the definite advantage given by improved methods is apparent, then the necessary stimulus is given to proceed with further work despite the temporary inconvenience and cost to the weaver.

It is apparent from the above that a laboratory method of evaluating the effectiveness of sizing on warp yarns would be of immeasurable assistance to the weaving process. Kenk (2) says, "It should be possible to test the sizing effect with objective methods in order to choose the most effective sizing materials and additives." He goes on to say that the increase in breaking strength is often used as a judgement of sizing effect but that large scale tests have shown that a high increase in breaking strength is not always indicative of good weaving properties. Kenk (3) also states that, "Elongation would be a better measurement. However, there are also many cases in which high elongation occurs along with poor weaving properties." So a true evaluation of sized yarn cannot be obtained from the breaking strength or the elongation, and that only a partial test is obtained.

From a close observation of the weaving process it is apparent that the warp yarns are subjected to a great deal of abrasion from the action of the drop wires, heddles and reed. It is the starch film of the size compound that must resist this abrasion and it follows that a measurement of this abrasion resistance might well be a measurement of size efficiency.

Brown (4) lists the causes of warp breaks as (1) knots, (2) impurities, (3) soft yarn, (4) unknown, (5) abrasion, (6) twisted ends, and (7) taped ends. He further attributes the warp breaks due to abrasion, soft yarn, twisted ends and taped ends to poor sizing. His experiments show that 24.7 per cent of all warp breaks may be attributed to poor sizing, of which over half or 13 per cent is due to abrasion. Knots account for 20.8 per cent, impurities for 13 per cent, and unknown for 40.8 per cent of all warp breaks. It can be seen from these experiments, since slightly over half of all warp breaks due to sizing can be attributed to abrasion, that the abrasion resistance of the sized yarn and the weaveability of that yarn should make a correlation possible.

Stallings and Worth (5) and Kenk (6) have shown that abrasion tests of yarn can be translated to mill results with a certain degree of assurance. They, however, did not attempt to establish a correlation coefficient for the resulting correlation.

Baines and Steiger (7) found that the weaveability of a warp varied as a function of the per cent size on the warp. Figure 1 is the result of their work along this line. "The object in this case was to determine under what conditions the best weaving would be obtained, using a size composed of 90 per cent dry sago starch and ten per cent tallow, the cloth being the $49\frac{1}{2}$ in. Z . . . . Five beams (or half a set) were made at each of four size concentrations ranging from 4.5 to 8.0 per cent." The

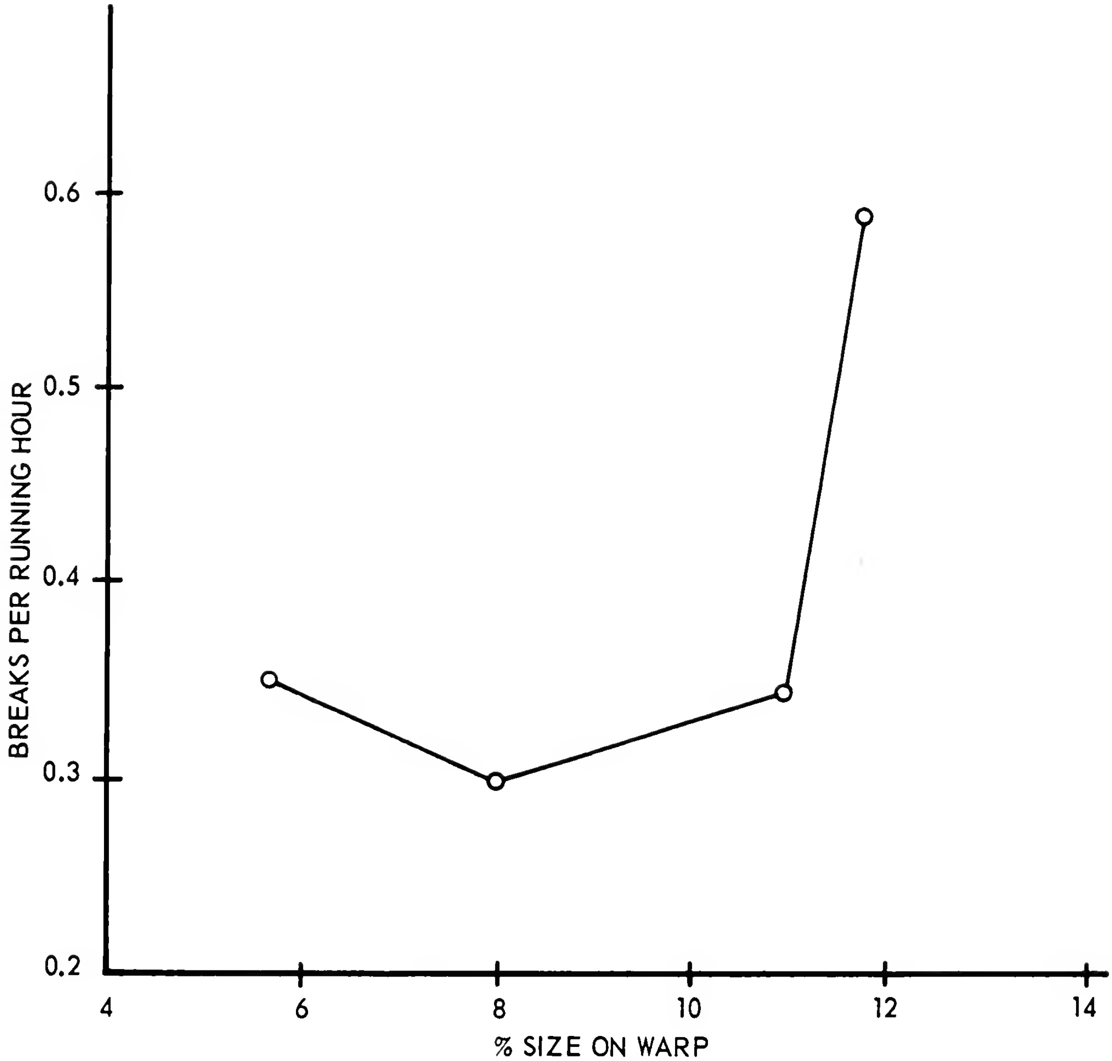

Figure 1. The Effect of Per Cent Size on Warp Stops per Loom Hour. Taken from Baines and Steiger, "Some Causes and Effects of Warp Breaks," Textile Institute Journal 40 (1949), p. 295.

concentrations, naturally, resulted in a different percentage size on the warp which was determined by the malting method. The warp breaks were counted through out each beam by the coloured thrum method. There was a total of 1,250 running hours of weaving at each concentration.

Baines and Steiger (8) also found that, "Undersizing has been rare in this mill, the tendency having been always in the other direction." This tendency seems to be found in practically all slashing operations.

The purpose of the study included in this work was to determine what correlation exists between the three yarn characteristics (tensile strength, elongation and abrasion resistance) and the weaveability of the same yarns. The coefficient of correlation will be established by the Product Moment Method of correlation.

The coefficient of correlation is a measure which describes the functional relationship between two variables. Other measures that fix the same relationship are the estimating equation and the standard error of estimate; however, both these measures have the disadvantage of being expressed in the units of the original data and also, that the equation for the line of estimate be known. For this study the original data for the two associated series will be in different units in each case. It is desired to state the degree of this relationship in concise numerical terms which are independent of the units of the original data, and since the coefficient of correlation is independent of the units of the original data it is apparently a better choice. (9)

The coefficient of correlation is a number varying from plus one, through zero, to minus one. The sign indicates whether the slope of the line of relationship is positive or negative, while the coefficient indicates the degree of correlation. When there is absolutely no relationship

between the variables, the coefficient of correlation (r) is zero.

It has been attempted in this study to take the test results for the yarn characteristics and correlate them with information pertaining to weaveability as collected from the mill furnishing the test yarns. This results in a coefficient of correlation that is capable of being compared with the other coefficients.

CHAPTER II

INSTRUMENTATION AND EQUIPMENT

Two major pieces of textile testing equipment were utilized in the experimental portion of this work. One was the Suter Single Strand Tester; and the other was an abrasion tester manufactured by K. Zweigle of Reutlingen, Germany. In addition, a de Khotinsky drying oven and a Christian Becker Chainomatic Balance were used.

Suter Single Strand Tester.--This instrument simply determines the breaking strength and elongation of a yarn. It is a low capacity, vertical pendulum type instrument, and it is a standard piece of testing equipment found in most textile testing laboratories. A complete description of the instrument is given in Haven's "Industrial Fabrics Handbook." (10)

The capacity of the single strand tester depends on the size of the weight that is attached to the pendulum. If no additional weight is attached to the pendulum the breaking strength capacity is a maximum of 500 grams; if the two-pound or twelve pound weight is attached to the pendulum the breaking strength capacity is a maximum of two or twelve pounds respectively. The allowable capacity of the machine is considered to be the dial readings included between nine and forty five degree swing of the pendulum.

There are two precautions necessary when testing with the single strand tester: (a) the speed of the lower jaw must be twelve plus or minus one sixteenth inches per minute and (b) specimens that break within

one-half inch of the jaws should be discarded. (11) If these precautions are observed in operating the single strand tester, the resultant breaking strength will be as accurate as can be obtained on this type of an instrument.

Zweigle Abrasion Tester.--This test instrument is new to the family of textile testing equipment. Up until the introduction of the Zweigle Tester the existing abrasion testers for yarns all had the disadvantage of abrading two or three test yarns at one time. Tests, with these instruments, therefore, did not permit the rapid determination of results. Fig. 2 and 2a shows the new abrasion tester. Twenty yarns or five strips of material (5 cm. wide) can be tested on this machine at the same time.

The functioning of the instrument is as follows: A cylinder, which is wrapped with an abrasive paper, moves horizontally in a straight line with a back and forward stroke of about eight centimeters. This cylinder is underneath and in contact with the yarn that is being tested. The material being tested determines the fineness of the paper to be used upon the cylinder. For example: for yarn number 40 and finer the grain should be 500A and for lower numbered yarn the paper should be correspondingly coarser. The cylinder, by the action of a ratchet and pawl arrangement, rotates about its own axis and in this way a fresh abrasive surface is continually present. A complete rotation is made for every twenty horizontal strokes of the cylinder. This is particularly important because in tests which last a long time or on material which is gummy or contains wax or fat, such as sized yarns, the abrasive surface of the paper would become filled with small particles of fibers, waxes or fats if the surface was not changed, thus, causing a corresponding change in the abrasive

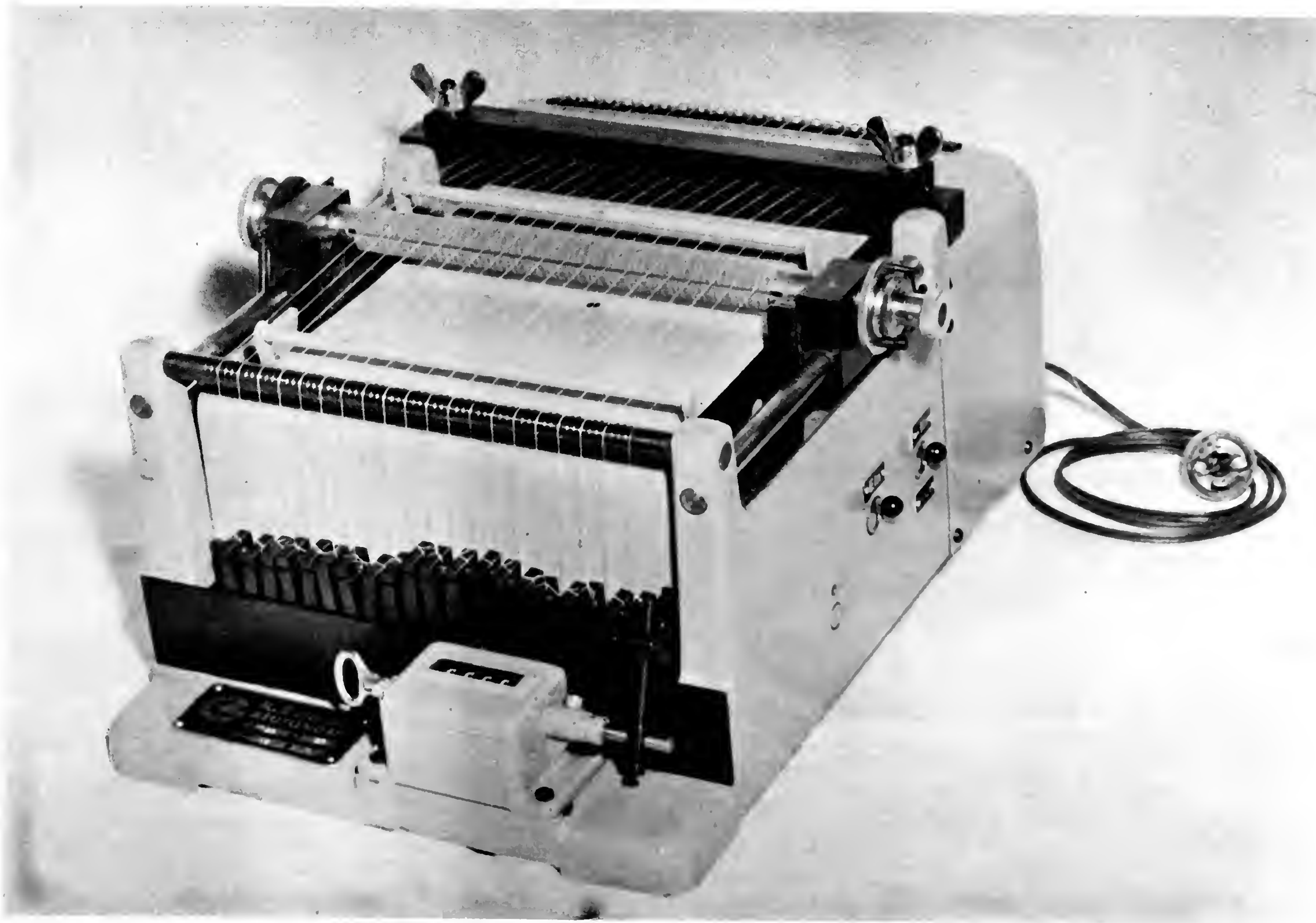

Figure 2. Zweigle Abrasion Tester with test yarns.

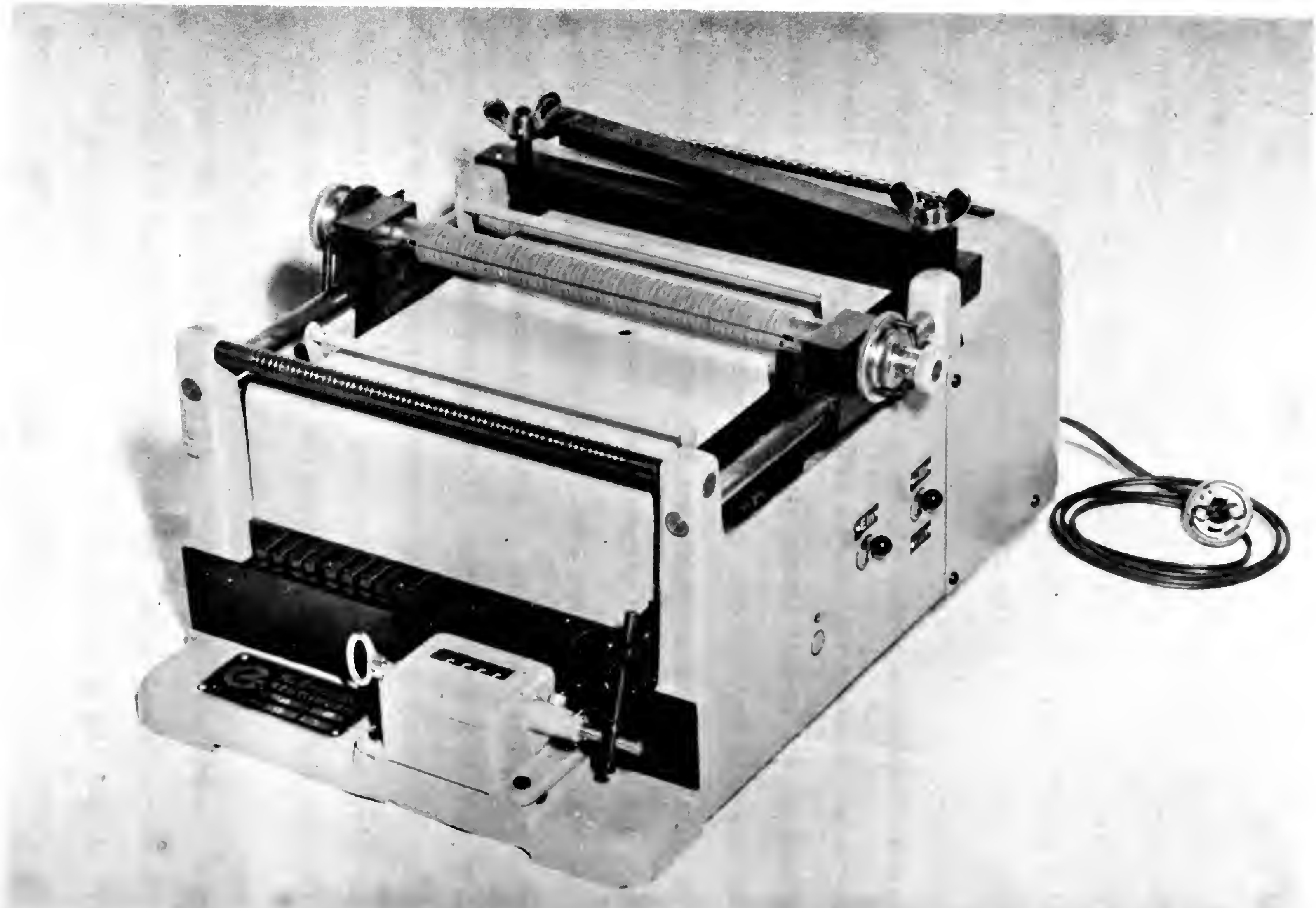

Figure 2a. Zweigle Abrasion Tester without test yarns.

effect. The abrasive paper is easily changed.

On the back side of the instrument is a clamp for holding the yarns in a fixed position. Farther back toward the rear of the instrument there are twenty nipples around which individual yarns are secured until all of them can be clamped in position. The yarns extend from the clamp over the abrasive cylinder to the front of the instrument where they are individually tied to one of the twenty weights which are near the bottom front of the machine.

The cylinder is driven by a small electric motor which is equipped with a small resistance control. This permits the speed of the abrading cylinder to be varied from 60 cycles per minute (a complete stroke back and forth) to 80 cycles per minute. It is also equipped with a counter so that the cycles to break for each end may be easily recorded.

For testing sized yarns, three lengths of yarn of about 40 centimeters is tied to one of the weights. This results in three ends of the yarn of about 40 centimeters being tied to each weight. To thread the instrument, one end from each weight is drawn across a guide rod on the front of the machine, across the abrasive cylinder and across the clamp to the nipples on the back of the machine where they are securely fastened. The clamp is secured by means of two winged nuts and the set of yarns is then ready to be tested.

After the twenty yarns have been threaded in this manner, the motor is turned on and the abrasive paper then rubs along the underside of the yarns. As soon as the yarn has been abraded to the extent that it will no longer support the weight, the weight falls, striking a plate. When the weight strikes the plate the resultant "bing" calls the attention of

the operator to read the counter which is attached to the abrasive cylinder, and record the number of cycles made by the instrument prior to the end breaking. The machine runs continuously until all twenty ends have been broken and the number of cycles necessary to break each end ascertained and recorded.

After the first twenty yarns have been tested a second yarn of the original yarns on each weight is laid across the abrasive cylinder of the instrument as previously described and tested. The cycles necessary to break each end recorded in the same manner as with the first yarn. This is repeated for the third yarn.

The clamp and the rod across the front of the machine on which the yarns are laid have 60 notches with which to hold the yarn in position. On the first set of twenty yarns they are laid in notches 1, 4, 7, 10, etc.; on the second set they are laid in notches 2, 5, 8, 11, etc.; and on the third set they are laid in notches 3, 6, 9, 12, etc. This allows all three sets to be run without moving or replacing the abrasive paper. In this manner, as many as nine abrasion tests can be carried out without replacing the abrasive paper. Care must be taken to lay each yarn in the same notch in both the clamp and rod. Should this not be done, the abrasive cylinder would present a greater surface to the test yarns, thereby, causing the abrasive effect to be increased.

CHAPTER III

PROCEDURE

The initial problem to be solved in this study was to determine the number of different test yarns necessary to indicate a trend, if one existed. It was decided that six sized yarns which had as nearly the same physical characteristics as possible be chosen with the hope that an indication of a trend would be present. It was necessary that each of the different yarns be sized with an entirely different size formula; and for each yarn the weaving qualities must be known. Therefore, to satisfy these factors it was necessary to procure each of the sample yarns from a different mill, since individual mills use approximately the same size formula for all the yarns used. This fact created a difficult problem in the procurement of test yarns and was the reason for the small number of samples. In the process of procuring the yarns six mills that were weaving warp yarns of about the same counts possessing the same general physical characteristics were contacted and ample yarns for the tests were supplied.

The yarns used in this problem were all taken from the warp beam from which they were being woven just after the beam's removal from the loom. In other words, the sample yarns were from the tail-end of a warp that had been actually woven. All figures on the weaving characteristics and physical properties were taken as being the best mill average for the part of the mill running the particular yarn used in this work.

Four of the yarn samples procured were 16's counts and the other two were 15's and 17's respectively. Five of the sample yarns had characteristics that were not significantly different; however, for the sixth sample yarn (the 15's), although all other characteristics were about the same as the 16's and 17's yarn, the break factor was considerably higher.

The weaveability of the yarn samples was accepted as being the number of warp stops per loom hour, and for the six yarn samples it ranged from 0.32 warp stops per hour (the best weaving) to 2.33 warp stops per hour (the poorest weaving).

Description of Yarn Samples Tested

The following is a description of the six sample yarns used in this work. All the yarn characteristics and weaving properties pertinent to this problem are enumerated.

Description of yarn sample A.--

Yarn counts	15's
Twist per inch	18.6
Size formula	140 gallons finish 140 pounds starch (Victor Mills 60) 13 pounds Hoaghton 30 103 gallons of water
Yarn strength	160-163 pounds (skein)
Break Factor	2430
Fabric construction	39"-43x136-1.90
Loom efficiency	92%
Warp stops per loom hour	0.32

Description of yarn sample B.--

Yarn counts	16's
Twist per inch	17.2
Size formula	220 gallon finish 200 pounds Pearl starch 16 pounds Texol 82 2 pounds Soft CX 1 pound Diocide Pellet 2 pounds Milwax
Yarn strength	122 pounds (skein)
Break Factor	1952
Fabric construction	39"-48x48-2.85
Loom efficiency	92%
Warp stops per loom hour	0.35

Description of yarn sample C.—

Yarn counts	17's
Twist per inch	18.7
Size formula	218 gallons finish 200 pounds Pearl starch 20 pounds Weavewell, L.S. number 8 compound 1 pint kerosene (Homogenized)
Yarn strength	118 pounds (skein)
Break Factor	2006
Fabric construction	53"-96x60-1.12
Loom efficiency	92%
Warp stops per loom hour	0.43

Description of yarn sample D.—

Yarn counts	16's
Twist per inch	19.1
Size formula	315 gallons finish 300 pounds starch 35 pounds Seyco #18 8 pounds wax (Homogenized)
Yarn strength	120 pounds (skein)
Break Factor	1920
Fabric construction	52"-81x36-1.59
Loom efficiency	85%
Warp stops per loom hour	0.77

Description of yarn sample E.--

Yarn counts	16's
Twist per inch	19.0
Size formula	175 gallons finish 175 pounds Pearl starch 20 pounds Weavewell 10 pounds emulsified wax 129 gallons water
Yarn strength	117 pounds (skein)
Break Factor	1872
Fabric construction	56"-103x66-1.14
Loom efficiency	86%
Warp stops per loom hour	0.84

Description of yarn sample F.--

Yarn counts	16's
Twist per inch	20.3
Size formula	300 gallons finish 260 pounds starch 26 pounds Disco Tallow
Yarn strength	120 pounds (skein)
Break Factor	1920
Fabric construction	48"-78x34-1.4455
Loom efficiency	87%
Warp stops per loom hour	2.33

Experimental Method

General.--All of the testing, with the exception of the desizing, was conducted in a laboratory equipped with an air conditioning unit which conditioned the atmosphere to the standard conditions of 65 per cent relative humidity and 70 degree Fahrenheit. (12) All yarn samples were allowed to become conditioned to the standard condition by remaining in the laboratory at least twenty-four hours prior to testing.

Tests for Abrasion Resistance.--All tests for abrasion resistance were conducted at standard conditions on the Zweigle Abrasion Tester described in Chapter II. Since a 500A grit abrasive paper is recommended for a 40's and finer count yarn, it was necessary to use a coarser paper to abrade the 15's, 16's and 17's yarn used in this problem. Several different papers having different grit (from 300 to 500) were tried and it was found that a 400 grit paper gave a resultant abrasion resistance with a range from approximately 100 to 1,000 cycles and an average of around 400 cycles for this count yarn. Therefore, an abrasive paper of 400 grit was used to abrade all six yarn samples used in this problem.

The abrasion tester was run at 80 cycles per minute for all samples.

The instrument was set up by tying three ends of about twenty inches in length to each of the twenty weights of the machine. One yarn from each of the twenty weights was then laid across the abrasive cylinder as described in Chapter II. The yarns were abraded until all the ends had broken, at the same time recording the number of cycles necessary to break each end. After all twenty ends had broken the remaining yarn from

the broken ends was removed and another end from each of the weights was laid across the abrasive cylinder and abraded in the same manner as before. After the third end from each weight had been abraded and the results recorded another three ends were tied to the weights and the process repeated. This was done four times for each sample, consequently, 120 ends were abraded for each sample of yarn. From this data the average number of cycles necessary to break the yarn was calculated. In addition, the standard deviation was calculated and a cumulative frequency table and curve was prepared for each of the sample yarns.

<u>Tests for Tensile Strength and Elongation</u>.—One hundred and twenty ends were taken from the individual yarn samples and broken using a Suter Single Strand Tester described in Chapter II. A ten-inch jaw distance was used for all break tests. The testing precautions mentioned in Chapter II were observed.

The tensile strength and elongation were recorded for each valid break; and the average, standard deviation, and range were calculated for each yarn sample.

<u>Per Cent Size on the Yarn</u>.—The per cent size on each of the warp yarn samples was determined by the alkali-acid method as outlined by the ASTM Standards on Textile Materials (D 334-40). (13)

CHAPTER IV

RESULTS

General.—All the results of the experimental portion of this study have been tabulated and prepared in table form and are included either in the text or in the appendix of this report. All the statistical calculations were accomplished by the short method for grouped and coded data. (14)

Results of the Abrasion Resistance Tests.—The original data for the abrasion resistance tests are included in tables 5 through 10 in the appendix. Tables 17 through 22 in the appendix gives the frequency distribution, the calculation of the mean and the standard deviation, and the comulative frequency for the abrasion resistance of the six sample yarns tested.

To calculate a coefficient of correlation r between the weaveability and the abrasion resistance it was necessary to find a number that would describe both parameters adequately. As previously mentioned the warp stops per loom hour give a fair estimate of the weaveability in terms of the weaving qualities of the warp. To describe the abrasion resistance two numbers were available; the arithmetic average and the sum of the cumulative frequencies.* The arithmetic average does not take into consideration the deviation from the average, whereas, the sum of the cumulative frequencies gives an index number that describes the abrasion

*Cumulative frequency refers to the total number of ends that broke at less than any specified number of cycles.

resistance and also allows for the deviation from the average. This is an inverse relationship, or in other words, the higher the number the smaller the abrasion resistance. Figure 3 shows the cumulative frequency curves for the six sample yarns. Table 1 lists the weaveability (X) and the abrasion resistance (Y) for the six individual yarns. Figure 4 shows the scatter diagram for these six points when the weaveability (X) is plotted against the abrasion resistance (Y). The coefficient r, calculated by the product moment method (15), is calculated as follows:

To calculate the coefficient of correlation by the product moment method it is necessary to know the sum, the sum of the squares and the sum of the product of the weaveability (X) and the abrasion resistance (Y). This information is given by table 1. The formula for calculating the coefficient is

$$r = \frac{P}{\sigma_x \; \sigma_y} \quad *$$

Where, for ungrouped data

$$P = \frac{\Sigma(XY)}{N} - \left(\frac{\Sigma(X)}{N}\right)\left(\frac{\Sigma(Y)}{N}\right) \quad **$$

$$\sigma_x = \sqrt{\frac{\Sigma(X^2)}{N} - \left(\frac{\Sigma X}{N}\right)^2} \quad ***$$

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* r = coefficient of correlation.

** P = product moment.

*** σ_x = standard deviation of (X).

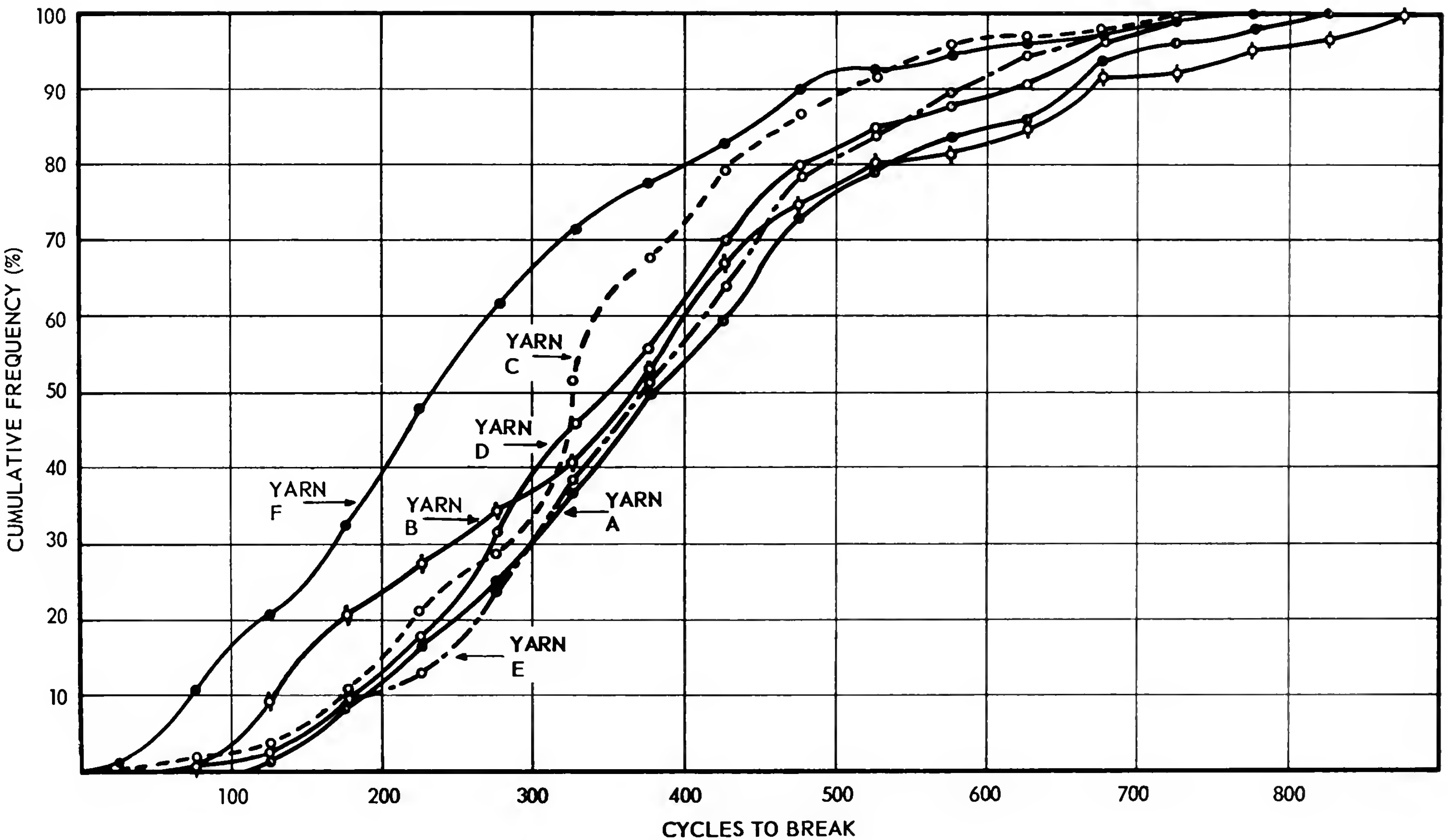

Figure 3. Cumulative Frequency Curves for Abrasion Resistance.

Table 1. Weaveability and Abrasion Resistance

Yarn No.	Weaveability (warp stops per loom hour) (Y)	(Y^2)	Abrasion Resistance (Cycles) (X)	(X^2)	(XY)
A	0.32	0.1024	1488	2,214,144	476.16
B	0.35	0.1225	1500	2,250,000	525.00
C	0.43	0.1849	1599	2,556,801	687.57
D	0.77	0.5929	1532	2,347,024	1,179.64
E	0.84	0.7056	1496	2,238,016	1,256.64
F	2.33	5.4289	1766	3,118,756	4,114.78
TOTALS	5.04	7.1372	9381	14,724,741	8,239,79

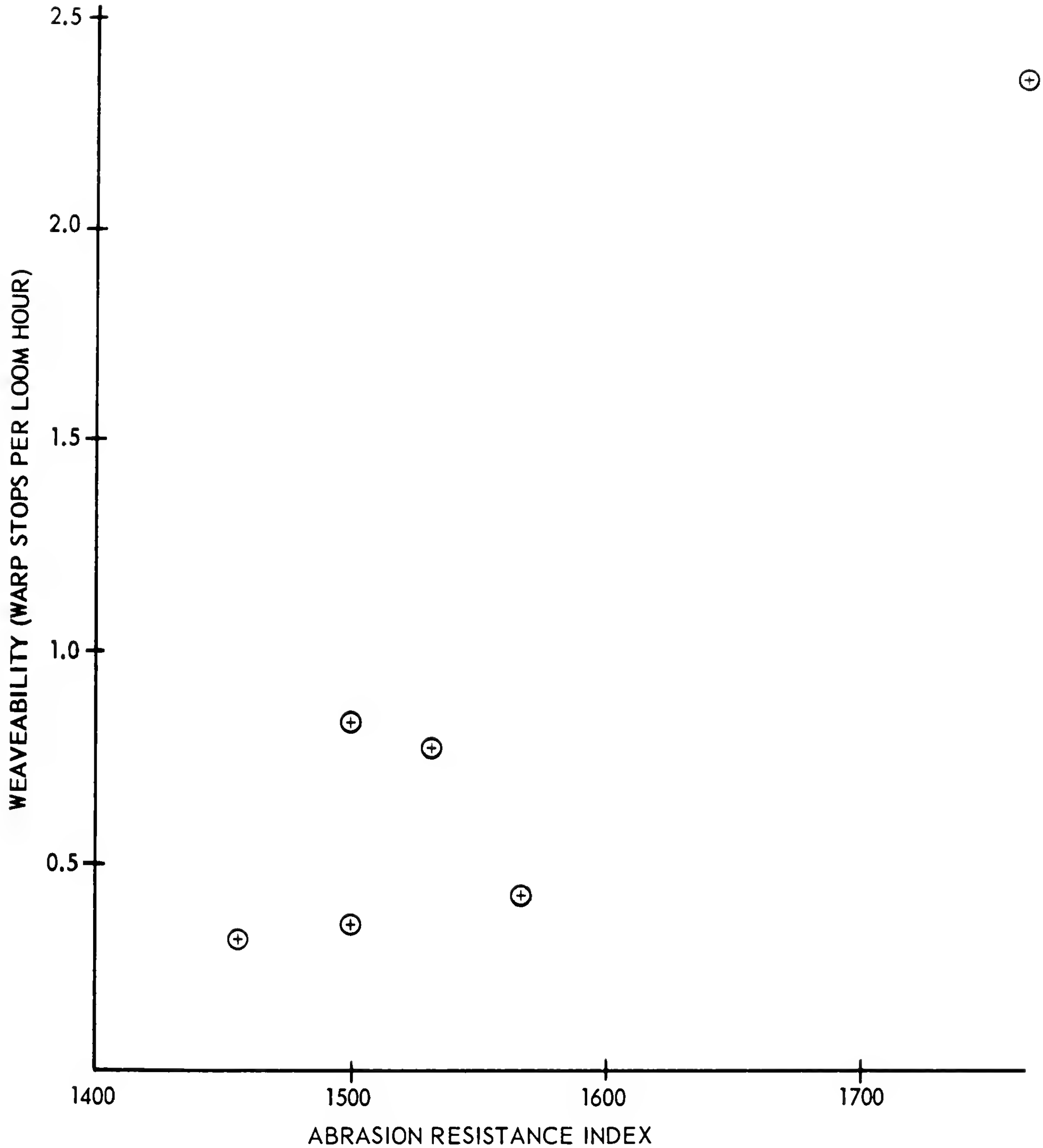

Figure 4. Scatter Diagram for the Weaveability Plotted Against the Abrasion Resistance.

$$\sigma_y = \sqrt{\frac{\Sigma(Y^2)}{N} - \left(\frac{\Sigma(Y)}{N}\right)^2}\ *$$

Therefore

$$P = \frac{8239.79}{6} - \frac{9381}{6} \times \frac{5.04}{6} = 59.96$$

$$\sigma_y = \sqrt{\frac{7.1372}{6} - \left(\frac{5.04}{6}\right)^2} = 0.6956$$

$$\sigma_x = \sqrt{\frac{14,724,741}{6} - \left(\frac{9381}{6}\right)^2} = 97.93$$

$$r = \frac{59.96}{97.93 \times 0.6956} = 0.88$$

In order to determine whether or not an observed correlation is significantly greater than zero, a procedure may be used which is applicable to both large and small samples. This method consists in computing the value of t from the expression

$$t = \frac{r\sqrt{N - 2}}{\sqrt{1 - r^2}}\ . \quad (16)^{**}$$

Then by consulting a table of t values, which refers to the values of t and n ($n = N - 2$), it can be determined how many times in 100 a sample drawn from a population with zero correlation would result in a correlation coefficient as high as that actually obtained.

---

*σ_y = standard deviation of (Y).

**t = ratio of a statistical measure which is distributed normally around a mean of zero to an estimate of the standard error of that measure based on the number of degrees of freedom present.

$$t = \frac{0.88\sqrt{4}}{\sqrt{1 - .7744}} = 3.495$$

Now from the t table (17) it was ascertained that there is slightly less than three chances in 100 ($P = 0.0278$) that a sample drawn from a population with zero correlation would result in a coefficient of correlation r as high as that obtained (0.88). Since this chance is rather small the correlation is assumed to be significant.

Results of Tensile Strength Tests.—The original data for the tensile strength tests are included in tables 11 through 16 in the appendix. Tables 23 through 28 in the appendix gives the frequency distribution and the calculation of the average and standard deviation for the tensile strength for the six individual sample yarns. A coefficient of correlation for the relationship between the tensile strength and the weaveability was calculated in the same manner as the coefficient of correlation for the abrasion resistance.

The data necessary to make this calculation are included in table 2. Figure 5 gives the scatter diagram for the weaveability plotted against the average tensile strength. The calculations for the coefficient of correlation r was accomplished as follows:

$$P = \frac{6.1466}{6} - \frac{5.04}{6} \times \frac{7.70}{6} = 0.0533^{*}$$

$$\sigma_x = \sqrt{\frac{9.9470}{6} - \left(\frac{7.70}{6}\right)^2} = 0.1044$$

---

*This relationship is inverse. The higher the tensile strength the lower the warp stops per loom hour.

Table 2. Weaveability and Tensile Strength

Yarn No.	Weaveability (warp stops per loom (Y)	(Y^2)	Tensile Strength (Pounds) (X)	(X^2)	(XY)
A	0.32	0.1024	1.46	2.1316	0.4672
B	0.35	0.1225	1.28	1.6384	0.4480
C	0.43	0.1849	1.37	1.8769	0.5891
D	0.77	0.5929	1.24	1.5376	0.9548
E	0.84	0.7056	1.20	1.4400	1.0080
F	2.33	5.4289	1.15	1.3225	2.6795
TOTALS	5.04	7.1372	7.70	9.9470	6.1466

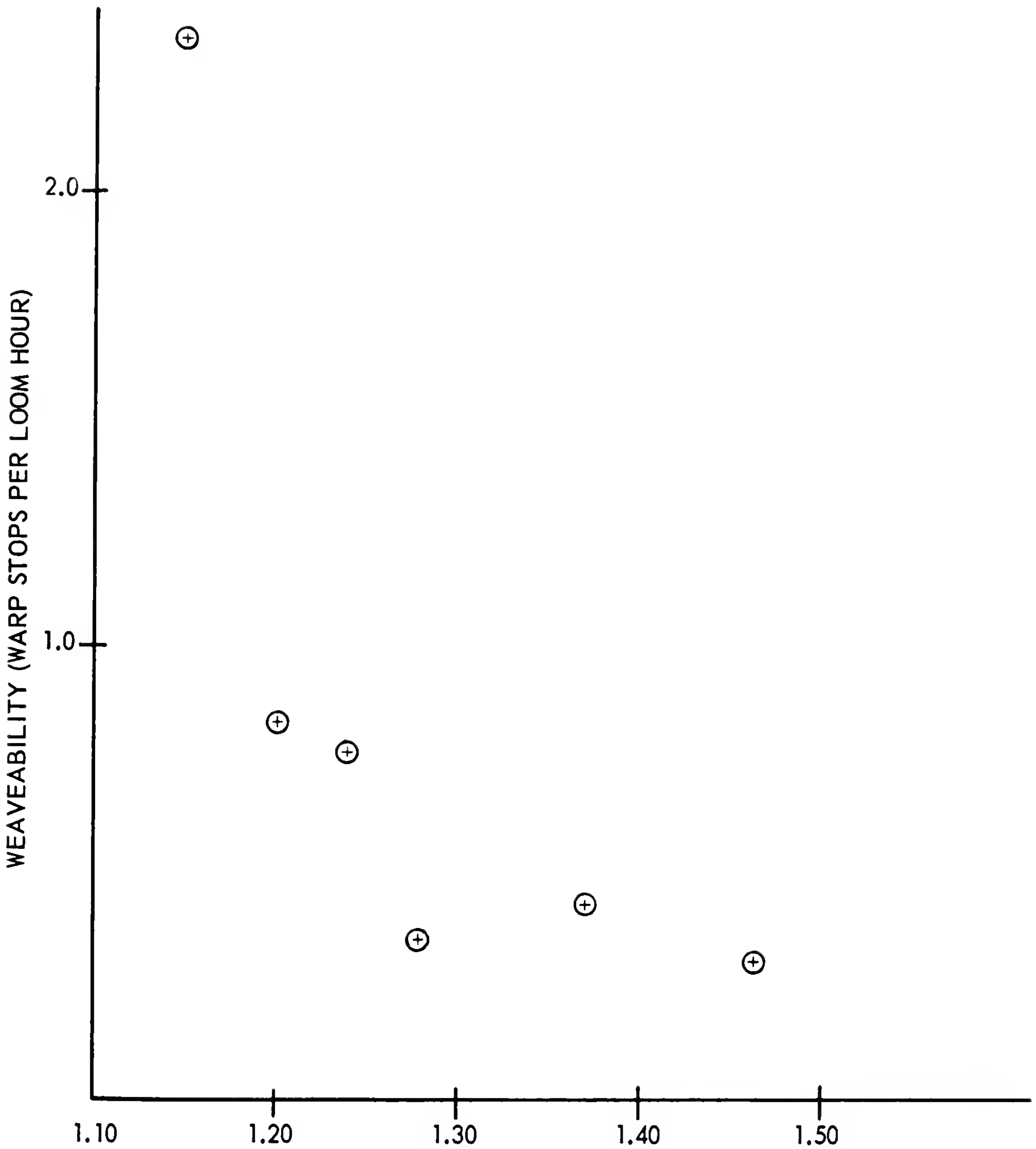

Figure 5. Scatter Diagram for Weaveability Plotted Against Tensile Strength.

$$\sigma_y = 0.6956 \text{ (From the calculations for abrasion resistance)}$$

$$r = \frac{-0.0533}{0.6956 \times 0.1044} = -0.76$$

To test for significance

$$t = \frac{0.76 \sqrt{4}}{\sqrt{1 - 0.5776}} = 3.598$$

From the t table (18) it was ascertained that there is slightly less than three chances in 100 ($P = 0.0246$) that a sample drawn from a population with zero correlation would result in a coefficient as high as that obtained (-0.76). Therefore, the coefficient is assumed to be significant.

<u>Results of Elongation Tests</u>.--The original data for the elongation tests are included in tables 11 through 16 in the appendix. Tables 19 through 34 in the appendix gives the frequency distribution and the calculation of the average and standard deviation for the elongation of the six sample yarns.

The coefficient of correlation for the relationship between the weaveability and elongation was calculated in the same manner as the coefficient of correlation for both the abrasion resistance and the tensile strength. The data required to make this calculation are included in table 3. Figure 6 gives the scatter diagram for the weaveability plotted against the elongation. The calculation of the coefficient of correlation r was accomplished as follows:

$$P = \frac{22.46}{6} - \frac{5.04}{6} \times \frac{27.45}{6} = -0.11$$

Table 3. Weaveability and Elongation

Yarn No.	Weaveability (Warp stops per loom hour)		Elongation (Per Cent)		
		(Y^2)	(X)	(X^2)	(XY)
A	0.32	0.1024	5.51	30.36	1.76
B	0.35	0.1225	4.75	22.56	1.66
C	0.43	0.1849	4.05	16.40	1.74
D	0.77	0.5929	4.49	20.16	3.46
E	0.84	0.7056	4.24	17.98	3.56
F	2.33	5.4289	4.41	19.44	10.28
TOTALS	5.04	7.1372	27.45	126.90	22.46

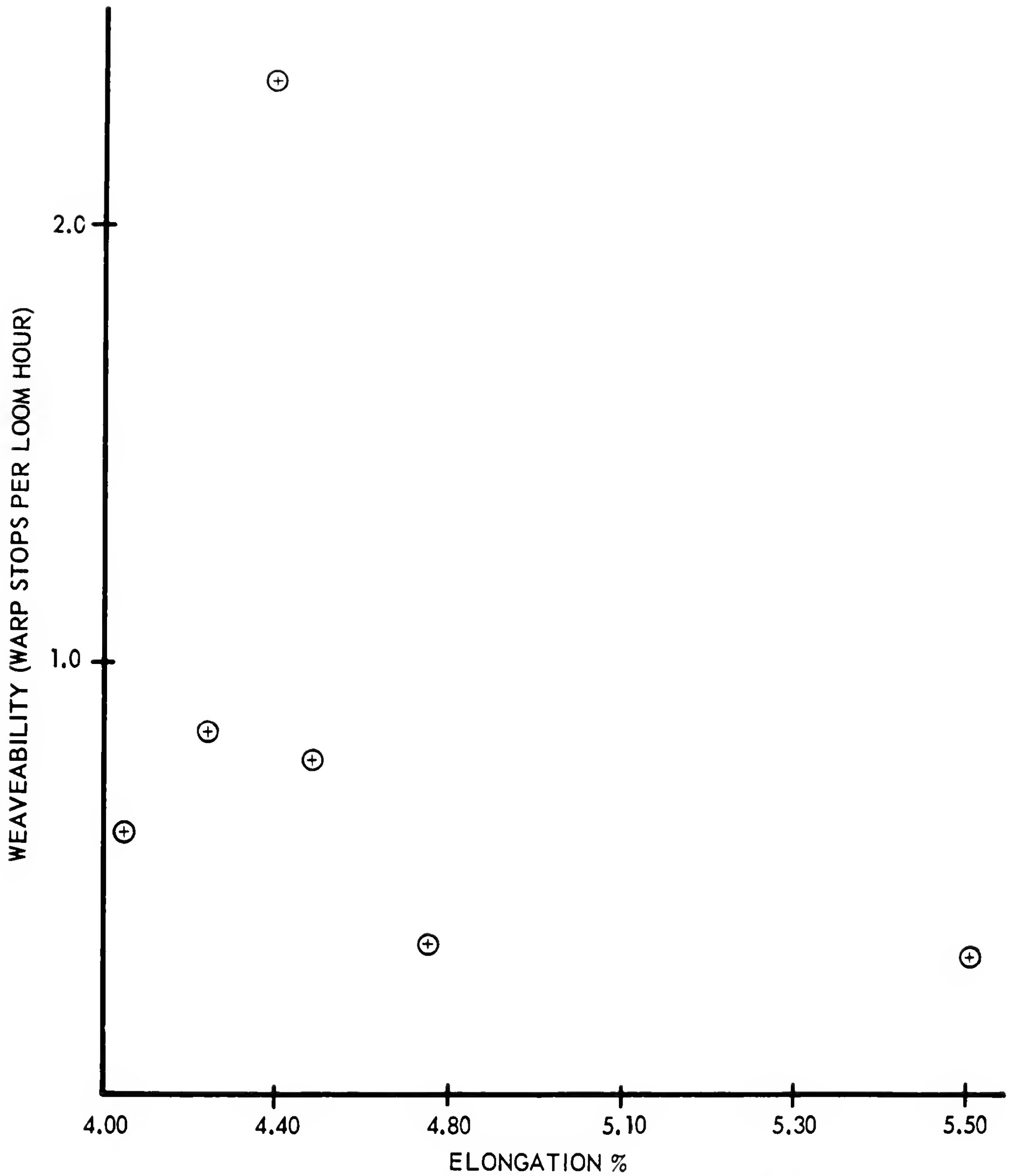

Figure 6. Scatter Diagram for Weaveability Plotted Against Elongation.

$$\sigma_x = \sqrt{\frac{126.9}{6} - \left(\frac{27.45}{6}\right)^2} = 0.4123$$

$$\sigma_y = 0.6956 \text{ (Same as for abrasion resistance)}$$

$$r = \frac{-0.11}{0.6956 \times 0.4123} = -0.38$$

To test for significance

$$t = \frac{0.38 \quad 4}{1 - 0.1444} = 0.812$$

From the t table (19) it was found that there were from 40 to 50 chances in 100 that a sample drawn from a population with a zero correlation would result in a coefficient of correlation r as high as that obtained (-0.38). Therefore, it is assumed that the resultant correlation is not significant.

Results for Per Cent Size on the Sample Yarns.—Table 4 gives the results for the tests to determine the per cent size on each of the sample yarns.

Table 4. Per Cent Size on Sample Yarns

Yarn No.	% Size Run 1	% Size Run 2	Total	Average	% Error
A	14.15	13.35	27.50	13.75	2.90
B	16.32	15.32	31.64	15.82	5.53
C	14.43	14.39	28.82	14.41	0.14
D	14.74	13.76	28.50	14.25	2.49
E	13.91	12.30	26.21	13.10	6.14
F	15.09	15.22	30.31	15.15	0.76

NOTE: (1) This includes the natural waxes and fats contained in the raw cotton.

(2) Per cent error $= \frac{\text{\% Size Run 1} - \text{\% Size Run 2}}{\text{\% Size Run 1} \quad \text{\% Size Run 2}}$

<u>The Calculation of the Coefficient of Correlation between Tensile Strength and Abrasion Resistance</u>.—The information necessary to make this calculation was taken from table 4a. For the purpose of calculating the coefficient, X will represent the tensile strength and Y the abrasion resistance.

Table 4a. Tensile Strength and Abrasion Resistance

Yarn No.	Tensile Strength (Pounds) (X)	(X^2)	Abrasion Resistance (Cycles) (Y)	(Y^2)	(XY)
A	1.46	2.1316	1488	2,214,144	2172.48
B	1.28	1.6384	1500	2,250,000	1920.00
C	1.37	1.8769	1599	2,556,801	2190.63
D	1.24	1.5376	1532	2,347,024	1899.68
E	1.20	1.4400	1496	2,238,016	1795.20
F	1.15	1.3225	1766	3,118,756	2030.90
TOTALS	7.70	9.947	9381	14,724,741	12,008.89

$$P = \frac{12,008.89}{6} - \left(\frac{7.70}{6}\right)\left(\frac{9381}{6}\right) = -4.96$$

$$\sigma_x = \sqrt{\frac{9.947}{6} - \left(\frac{7.70}{6}\right)^2} = 0.1044$$

$$\sigma_y = \sqrt{\frac{14,724,741}{6} - \left(\frac{9381}{6}\right)^2} = 97.9345$$

$$r = \frac{-4.96}{97.9345 \times 0.1044} = -0.485$$

To test for significance

$$t = \frac{0.485\sqrt{6 - 2}}{\sqrt{1 - (0.485)^2}} = 1.1106$$

From the t table (20) it was found that there were from 30 to 40 chances in 100 that a sample drawn from a population with a zero correlation would result in a coefficient of correlation as high as that obtained (-0.485). Therefore, it is assumed that the correlation is not significant.

CHAPTER V

DISCUSSION OF RESULTS AND CONCLUSIONS

It was stated in Chapter I that the purpose of this study was to determine the relationship between the weaveability and the three yarn characteristics (tensile strength, elongation and abrasion resistance) of sized warp yarns. Also, the hypothesis was made that abrasion resistance could be used as a laboratory method of evaluating sized warp yarn, should a definite correlation exist between the weaveability and the abrasion resistance. This study has attempted to establish this correlation by using yarns and data from local mills.

The results show a definite correlation between the weaveability and both the tensile strength and abrasion resistance; however, there is little indication of a correlation between the weaveability and the elongation.

It is well established that the relationship between the weaveability and both the tensile strength and elongation is not such as to warrant their use as a method of evaluating warp sizing. From the results obtained in this study a good relationship was found to exist between the weaveability and tensile strength (0.76); and a poor relationship was found to exist between the elongation and the weaveability (0.38). This is not in accord with most authorities, since they agree that elongation should be the better measure to evaluate the weaveability of a sized yarn (see p. 3, Chapter I).

The correlation between the tensile strength and abrasion resistance (-0.485) was found to be poor and not significant. On this basis it is assumed that tensile strength and abrasion resistance are two independent variables.

The relationship between the weaveability and abrasion resistance (0.88) obtained as a result of this experiment was only slightly better than that obtained for the relationship between weaveability and tensile strength (0.76). Both of these relationships are statistically significant. In Chapter I it was stated that tensile strength or elongation was not a good measure for evaluating warp size and since there is no appreciable difference in the relationship between weaveability and tensile strength and the relationship between weaveability and abrasion resistance it can be concluded that either insufficient samples were used in this attempt or that the abrasion resistance of a sized warp yarn is not a good measure for the evaluation of a warp size, per se.

However, the above may be qualified by the fact that although the poorer weaving yarn (Yarn F) was not significantly poorer in tensile strength or elongation, it was considerably poorer in abrasion resistance. This is not easily explained. The results of tests for determination of the percentage size on the yarn does not indicate that the amount of size would give such a trend. It was thought that penetration could give a clue to the solution; however, due to the non-uniformity of the yarn, it was not possible to establish this relationship. In considering the type of size formula used on the yarns it is apparent that the yarn that has the poorest weaveability and also the poorest abrasion resistance (Yarn F) was sized with an unmodified starch; whereas, the other yarns were all

either sized with a pearl starch or the starch was homogenized. This is an indication that penetration could have caused the difference in both the weaveability and the abrasion resistance.

It can, therefore, be concluded that abrasion resistance can conceivably be a method of evaluating a warp size in the laboratory, however, considerable work is still to be done to adequately develop a method that would be acceptable to the textile industry.

APPENDIX

Table 5. Original Data for Abrasion Resistance in Cycles for Yarn A

Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
158	169	148	194	182	191
172	177	184	292	219	200
205	203	219	302	287	220
216	227	241	313	301	243
228	270	299	387	347	273
288	280	323	362	350	295
315	286	337	446	352	315
348	300	340	487	397	405
368	312	354	494	400	406
391	318	370	513	448	423
399	356	372	554	451	467
423	377	381	559	466	471
455	389	396	654	479	491
457	390	438	660	541	499
468	405	468	668	563	505
498	436	480	670	579	572
514	441	491	674	678	627
523	450	519	692	684	704
658	485	601	744	707	757
659	540	630	837	808	839

Table 6. Original Data for Abrasion Resistance in Cycles for Yarn B

Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
88	148	103	141	132	139
150	164	134	141	139	159
168	183	247	161	149	190
189	230	271	181	165	213
262	245	310	185	169	228
270	284	356	188	174	231
297	330	366	234	189	253
385	355	368	253	219	278
401	383	389	324	322	325
433	404	391	331	347	334
454	411	401	356	354	363
465	420	434	387	355	365
556	442	460	399	409	407
695	447	467	418	420	429
732	454	531	421	460	432
736	463	545	436	470	476
806	531	609	510	636	506
855	666	635	677	655	519
859	753	647	867	671	553
950	795	798	1105	685	644

Table 7. Original Data for Abrasion Resistance in Cycles for Yarn C

Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
89	97	173	157	311	101
173	122	174	189	324	166
184	155	227	201	376	237
187	264	233	202	378	246
227	264	243	204	380	287
303	297	270	209	392	303
306	317	277	219	426	321
332	325	299	224	442	326
338	331	299	247	448	329
355	339	302	307	451	331
358	345	304	308	456	332
374	358	317	325	489	333
375	362	370	331	498	340
387	371	382	338	518	351
401	429	395	350	561	396
408	445	438	380	562	403
413	451	506	390	563	412
438	517	517	441	584	416
484	524	647	460	683	506
498	725	729	495	749	568

Table 8. Original Data for Abrasion
Resistance in Cycles for Yarn D

Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
81	162	209	100	189	184
256	169	265	106	205	199
260	178	286	195	240	222
280	188	291	199	248	262
283	217	300	207	253	283
299	288	309	218	266	291
312	291	312	230	307	301
324	311	321	275	340	307
351	333	327	308	375	347
379	347	329	317	387	358
417	392	381	329	391	360
426	433	401	375	454	415
438	444	449	399	475	421
441	465	454	428	486	423
447	476	455	431	566	448
448	487	460	449	609	452
461	577	487	458	641	453
519	654	681	546	649	489
557	676	688	719	649	586
670	696	720	732	752	672

Table 9. Original Data for Abrasion Resistance in Cycles for Yarn E

Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
175	197	196	158	199	168
200	200	197	199	265	196
212	217	251	245	268	209
311	288	278	262	268	267
315	294	283	274	327	272
321	302	284	278	347	327
322	320	362	295	360	328
325	328	377	302	367	340
341	364	390	346	392	355
374	368	395	364	430	370
404	370	429	427	442	387
410	375	434	430	452	394
412	408	457	435	460	429
467	414	460	446	468	460
500	447	467	454	484	463
502	459	553	478	493	464
505	496	558	484	603	532
506	519	567	522	749	647
607	595	598	586	750	672
688	631	674	636	809	701

Table 10. Original Data for Abrasion
Resistance in Cycles for Yarn F

Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
93	80	79	91	41	70
201	100	83	123	76	96
200	124	84	165	114	114
227	162	97	167	122	125
243	181	99	206	147	143
268	183	138	222	154	163
276	193	139	229	195	188
277	213	147	248	204	218
283	227	150	257	219	222
292	288	166	272	221	235
305	307	181	285	259	240
338	330	184	308	262	273
350	344	208	331	291	293
433	353	222	339	301	298
466	370	254	375	379	309
476	379	269	447	416	315
492	420	484	470	433	326
500	458	512	519	446	356
596	522	700	626	481	454
735	794	994	637	554	680

Table 11. Original Data for Tensile Strength (pounds) and Elongation (per cent) of Yarn A

Test No.	T. S.	Elongation	T. S.	Elongation	T. S.	Elongation
1	1.57	6.75	1.64	7.50	1.45	5.75
2	1.39	6.25	1.65	5.50	1.26	4.75
3	1.56	5.25	1.38	5.75	1.34	5.25
4	1.63	5.50	1.71	6.25	1.56	5.75
5	1.54	5.50	1.53	6.75	1.44	5.50
6	1.77	6.50	1.37	5.00	1.38	5.25
7	1.39	6.00	1.38	5.50	1.44	5.75
8	1.79	6.75	1.50	6.00	1.23	5.00
9	1.58	6.75	1.50	6.00	1.54	6.25
10	1.36	5.50	1.40	5.75	1.47	6.00
11	1.38	6.00	1.43	6.25	1.09	4.25
12	1.40	5.00	1.43	6.00	1.16	4.50
13	1.51	6.75	1.22	4.75	1.33	4.75
14	1.49	6.00	1.36	5.00	1.21	5.25
15	1.28	5.50	1.28	4.75	1.24	5.00
16	1.37	5.75	1.32	5.00	1.50	5.50
17	1.50	6.00	1.66	6.50	1.46	5.75
18	1.77	6.00	1.29	4.50	1.53	5.50
19	1.36	6.00	1.29	4.50	1.48	5.00
20	1.37	6.25	1.55	5.50	1.56	6.25
1	1.80	6.50	1.50	5.75	1.55	5.75
2	1.50	6.00	1.41	5.75	1.65	6.50
3	1.56	6.50	1.60	5.25	1.37	6.25
4	1.71	6.50	1.59	5.50	1.42	4.75
5	1.51	6.00	1.49	6.25	1.67	6.75
6	1.37	5.25	1.29	4.75	1.29	4.75
7	1.46	5.75	1.47	4.50	1.30	5.75
8	1.67	6.25	1.46	4.75	1.28	5.25
9	1.56	6.00	1.66	6.25	1.56	6.00
10	1.63	6.00	1.58	6.00	1.60	6.50
11	1.37	5.50	1.39	5.75	1.61	6.00
12	1.62	7.00	1.20	4.75	1.70	5.75
13	1.21	4.75	1.54	5.50	1.59	6.00
14	1.66	6.50	1.34	5.50	1.36	5.50
15	1.56	6.00	1.40	5.25	1.38	5.50
16	1.53	6.00	1.73	5.50	1.66	6.50
17	1.45	6.00	1.49	5.50	1.56	4.75
18	1.24	4.25	1.61	6.00	1.46	6.00
19	1.29	4.50	1.23	5.25	1.54	4.50
20	1.61	5.50	1.23	4.25	1.55	4.50

Table 12. Original Data for Tensile Strength (pounds) and Elongation (per cent) of Yarn B

Test No.	T. S.	Elongation	T. S.	Elongation	T. S.	Elongation
1	1.25	4.75	1.15	4.00	1.24	4.75
2	1.34	5.75	1.54	6.25	.86	3.25
3	1.21	4.00	1.03	3.50	1.32	4.25
4	1.23	4.25	1.35	5.25	1.20	4.50
5	1.25	5.25	1.15	4.50	1.33	5.00
6	1.44	5.25	1.46	5.00	1.20	4.00
7	1.33	5.50	1.33	5.50	1.44	5.50
8	1.33	5.50	1.32	4.75	1.12	4.75
9	0.80	2.75	1.54	5.25	1.42	5.00
10	1.34	5.50	1.23	4.75	1.37	5.25
11	1.40	5.00	1.09	4.00	1.31	5.00
12	1.37	5.00	1.09	4.00	1.19	4.00
13	1.44	4.50	1.50	5.50	0.97	3.75
14	1.32	5.00	1.30	4.50	0.98	4.00
15	1.17	4.50	1.39	5.25	1.29	5.00
16	1.66	6.50	1.44	4.75	1.40	5.75
17	1.20	4.75	1.24	4.50	0.92	3.75
18	1.08	3.75	1.23	5.00	1.29	5.50
19	1.39	5.50	1.42	5.25	1.08	4.75
20	1.32	4.75	1.07	4.00	1.34	4.75
1	1.15	4.25	1.28	4.50	1.25	5.00
2	1.34	4.50	1.50	6.00	1.48	5.75
3	1.53	5.50	1.28	4.25	1.33	5.00
4	1.35	5.00	1.45	5.00	1.39	5.50
5	1.49	5.50	1.27	4.25	1.47	6.00
6	1.32	5.50	1.63	7.50	1.23	4.50
7	1.41	5.50	1.50	6.00	1.20	4.00
8	1.20	4.25	1.39	4.75	1.46	5.75
9	1.29	4.75	1.38	5.25	1.28	5.25
10	1.15	4.25	1.47	5.25	1.33	4.50
11	1.23	4.75	1.15	4.50	1.34	5.25
12	1.41	5.50	1.07	4.25	1.29	5.00
13	1.04	4.00	1.13	4.00	1.31	4.50
14	1.19	4.50	1.28	4.50	1.08	4.50
15	1.65	6.50	1.57	5.75	1.31	5.00
16	1.16	4.50	1.38	4.75	1.27	5.25
17	1.08	3.75	1.10	4.25	1.15	4.50
18	1.23	4.50	1.27	4.75	1.55	5.50
19	1.42	5.50	1.21	4.50	1.23	4.50
20	1.56	5.50	1.20	4.00	1.39	4.75

Table 13. Original Data for Tensile Strength (pounds) and Elongation (per cent) of Yarn C

Test No.	T. S.	Elongation	T. S.	Elongation	T. S.	Elongation
1	1.40	4.25	1.43	4.25	1.42	4.50
2	1.16	3.75	1.53	4.50	1.28	3.75
3	1.38	4.25	1.49	4.50	1.39	4.25
4	1.32	4.00	1.10	3.75	1.24	3.75
5	1.64	4.50	1.40	5.00	1.12	3.75
6	1.51	4.50	1.40	4.25	0.94	2.25
7	1.06	3.50	1.16	4.00	1.30	3.50
8	1.58	4.75	1.60	4.50	1.55	4.50
9	1.40	4.50	1.33	4.25	1.12	4.00
10	1.24	4.00	1.50	5.00	1.07	3.75
11	1.62	6.25	1.37	4.75	1.55	4.75
12	1.10	3.50	1.64	5.00	1.41	4.00
13	1.55	4.50	1.33	4.00	1.31	4.00
14	1.38	4.00	1.43	5.00	1.58	4.25
15	1.20	4.00	1.30	4.50	1.73	5.75
16	1.42	3.75	1.36	4.00	1.38	3.75
17	1.24	3.75	1.61	4.50	1.61	4.50
18	1.55	5.00	1.21	4.50	1.32	4.00
19	1.50	5.25	1.65	5.00	1.54	4.25
20	1.55	4.25	1.36	4.75	1.37	3.50
1	1.60	5.25	1.48	4.50	1.57	4.50
2	1.45	4.50	1.37	4.25	1.36	3.75
3	1.33	4.25	1.17	3.00	1.31	4.00
4	0.94	3.00	1.40	4.00	1.56	4.50
5	1.29	4.25	1.20	3.25	1.33	4.00
6	1.43	4.50	1.44	4.00	1.47	5.00
7	1.55	5.00	1.15	3.75	1.42	4.25
8	1.24	4.00	1.29	4.00	1.38	4.75
9	1.43	4.25	1.40	4.00	1.07	3.25
10	1.53	4.75	1.36	4.25	1.57	5.00
11	1.67	5.00	1.16	3.50	1.24	3.50
12	0.91	2.25	1.43	4.50	1.31	3.50
13	1.49	5.00	1.40	3.50	1.15	4.00
14	1.55	4.00	1.55	4.50	1.18	4.00
15	1.21	3.25	1.50	5.50	1.29	4.50
16	1.51	4.00	1.15	2.75	1.21	3.75
17	1.23	3.50	1.28	3.75	1.65	5.00
18	1.12	3.50	1.38	4.50	1.40	4.50
19	1.53	5.00	1.47	4.50	1.50	4.50
20	1.29	3.75	1.29	3.50	1.33	4.25

Table 14. Original Data for Tensile Strength (pounds) and Elongation (per cent) of Yarn D

Test No.	T. S.	Elongation	T. S.	Elongation	T. S.	Elongation
1	.98	3.00	1.15	4.00	1.12	4.75
2	1.07	2.50	1.39	5.25	1.07	3.25
3	1.12	4.00	1.12	4.25	1.46	4.50
4	1.11	4.00	1.24	4.00	1.07	4.00
5	1.19	4.25	1.55	6.00	1.11	4.50
6	1.37	5.00	1.28	5.25	1.36	6.00
7	1.10	4.00	1.16	4.50	1.20	4.25
8	1.24	5.00	1.30	4.00	1.17	4.50
9	1.24	5.00	1.34	5.00	1.16	5.00
10	1.30	5.00	1.20	4.25	1.29	5.50
11	1.21	3.50	1.22	4.00	1.09	3.75
12	1.20	4.00	1.48	5.25	1.33	4.75
13	1.14	3.75	1.22	4.50	1.21	5.00
14	1.18	4.00	1.23	6.00	1.44	5.25
15	1.32	4.50	1.23	5.25	1.18	4.00
16	1.27	4.75	1.32	5.50	1.54	6.25
17	1.37	5.25	1.07	4.00	1.52	5.00
18	1.32	5.00	1.18	3.25	1.28	5.00
19	1.14	4.25	1.18	3.75	1.55	5.75
20	1.43	4.75	0.75	2.00	1.40	5.25
1	1.28	4.25	1.33	5.00	0.98	4.00
2	1.24	4.00	1.38	5.50	1.18	4.50
3	1.38	6.00	1.23	4.75	1.33	4.50
4	1.28	4.25	0.94	3.50	1.10	4.25
5	1.32	5.25	1.06	4.00	1.39	5.25
6	1.40	5.00	1.30	4.25	1.35	5.50
7	1.32	5.50	1.40	6.00	1.24	5.25
8	1.26	4.75	1.27	4.75	1.31	5.50
9	0.95	3.75	1.51	5.50	1.25	4.25
10	1.34	4.50	1.37	5.50	1.13	5.00
11	1.09	4.50	1.00	4.00	1.47	6.50
12	1.43	5.00	1.22	4.75	1.06	4.50
13	1.30	5.00	1.18	5.00	1.11	4.50
14	1.48	5.75	1.24	4.50	1.16	5.50
15	1.38	5.50	1.29	5.00	1.48	5.00
16	1.10	3.75	0.88	2.50	1.14	3.50
17	1.27	4.75	1.04	4.00	1.46	6.00
18	1.33	5.25	1.20	4.75	1.30	5.50
19	1.24	4.00	1.50	5.50	1.38	6.25
20	1.34	3.25	1.21	4.25	1.19	4.00

Table 15. Original Data for Tensile Strength (pounds) and Elongation (per cent) of Yarn E

Test No.	T. S.	Elongation	T. S.	Elongation	T. S.	Elongation
1	1.43	6.25	0.91	3.50	1.37	4.75
2	1.09	5.00	1.17	4.75	1.20	3.50
3	1.17	3.75	1.13	4.50	1.34	4.50
4	1.50	6.00	1.18	5.25	1.24	3.75
5	1.10	5.00	1.15	4.50	1.04	3.50
6	1.16	4.50	1.23	4.50	1.01	4.00
7	1.12	4.25	1.09	4.50	1.13	5.25
8	1.21	3.75	1.27	4.25	1.24	4.25
9	1.16	3.75	0.94	2.50	0.95	3.00
10	1.24	4.75	1.38	5.50	1.37	4.50
11	1.38	4.50	1.09	3.75	1.39	5.00
12	1.34	5.00	1.23	3.50	1.31	4.25
13	1.22	5.25	1.15	3.75	0.91	3.25
14	1.21	3.25	1.15	4.25	1.36	5.25
15	1.20	4.25	0.89	3.50	1.09	4.25
16	1.32	4.75	1.04	4.00	1.37	5.75
17	1.33	4.50	1.18	4.00	1.51	6.00
18	1.16	4.25	1.43	6.00	1.34	5.25
19	1.07	4.50	1.31	5.25	1.27	4.75
20	1.27	4.75	1.11	3.75	1.23	5.00
1	1.13	4.25	1.17	3.50	1.21	4.50
2	0.88	3.00	1.19	5.25	1.08	4.25
3	1.47	5.00	1.08	4.00	1.11	3.50
4	1.15	4.50	1.15	4.25	1.28	4.75
5	0.98	4.25	1.37	5.00	0.91	3.75
6	1.23	4.50	1.40	5.00	1.26	5.25
7	1.38	5.50	1.25	4.00	1.35	5.50
8	1.21	4.00	1.32	5.00	1.19	4.00
9	1.31	4.75	0.94	4.00	1.54	6.50
10	1.35	5.50	0.91	3.50	1.12	4.00
11	1.13	4.75	1.15	4.50	1.50	5.50
12	1.18	4.75	1.23	3.50	1.19	4.50
13	1.14	5.00	1.12	4.50	1.18	3.75
14	1.31	4.75	1.20	4.75	1.55	6.00
15	1.37	5.00	1.30	4.75	1.16	4.25
16	1.23	4.75	1.16	3.50	1.15	3.50
17	1.24	5.00	1.28	4.75	1.21	5.25
18	1.50	4.75	.91	3.50	1.08	3.75
19	0.94	3.50	1.30	5.25	1.25	4.75
20	1.18	3.25	.88	3.00	1.06	4.00

Table 16. Original Data for Tensile Strength (pounds) and Elongation (per cent) of Yarn F

Test No.	T. S.	Elongation	T. S.	Elongation	T. S.	Elongation
1	1.12	4.25	1.20	4.75	1.17	4.00
2	1.28	4.75	1.11	5.00	0.88	3.75
3	1.40	5.00	0.97	3.50	1.08	4.00
4	1.04	4.50	1.15	5.00	1.03	4.00
5	1.34	5.50	1.21	4.00	1.16	4.50
6	1.13	4.75	1.54	5.50	1.33	5.25
7	1.50	6.00	1.13	3.25	0.95	3.50
8	1.14	4.50	0.82	3.00	1.36	4.75
9	1.04	4.50	0.98	3.75	0.98	3.75
10	1.31	5.25	1.08	4.00	0.99	4.00
11	1.33	5.25	1.13	4.50	1.20	4.75
12	0.80	2.75	1.13	4.25	1.12	4.75
13	1.17	4.75	1.35	4.50	1.14	4.75
14	1.18	4.75	1.24	4.25	1.16	4.00
15	1.43	5.50	1.19	4.75	0.93	3.75
16	1.05	5.00	1.01	3.75	1.16	4.50
17	1.14	4.25	1.14	4.50	1.19	5.00
18	1.04	4.00	1.28	5.00	0.99	3.75
19	1.01	4.50	1.33	5.50	1.26	4.50
20	0.80	3.25	0.86	3.25	1.28	5.00
1	1.30	5.75	1.20	5.25	1.19	4.50
2	1.17	5.00	1.00	4.50	1.18	5.00
3	1.63	5.75	1.17	4.00	1.13	5.25
4	1.12	5.25	.92	3.25	1.20	5.00
5	1.08	5.00	1.05	4.50	1.08	4.00
6	1.08	4.50	1.42	6.25	0.80	2.75
7	1.07	3.75	0.94	4.00	1.19	5.25
8	1.45	6.25	0.85	3.75	1.21	5.00
9	1.09	4.00	0.82	3.50	1.23	4.75
10	1.40	6.25	1.01	4.00	1.33	5.50
11	0.89	3.50	1.32	4.75	1.24	5.00
12	1.11	4.75	1.17	3.50	1.29	4.75
13	1.17	4.50	1.08	4.25	1.64	5.25
14	.96	4.50	1.21	5.75	1.27	4.00
15	1.29	5.50	1.31	5.00	1.50	5.50
16	1.05	5.00	1.08	4.50	1.10	4.25
17	1.07	5.00	1.19	4.75	1.05	5.00
18	1.12	4.50	.94	4.50	1.21	5.00
19	1.24	5.00	1.16	3.75	1.67	6.00
20	.92	3.50	1.18	3.75	1.04	4.50

Table 17. Frequency Distribution, Cumulative Frequency and the Calculation of the Average and Standard Deviation for the Abrasion Resistance of Yarn A

Class Interval (cycles)	Mid Point	Frequency (f)	x	fx	fx^2	Cumulative Frequency
0-50	25	0	- 7	0	0	0
51-100	75	0	- 6	0	0	0
101-150	125	1	- 5	- 5	25	1
151-200	175	9	- 4	-36	144	10
201-250	225	10	- 3	-30	90	20
251-300	275	10	- 2	-20	40	30
301-350	325	14	- 1	-14	14	44
351-400	375	16	0	0	0	60
401-450	425	11	1	11	11	71
451-500	475	17	2	34	68	88
501-550	525	7	3	21	63	95
551-600	575	5	4	20	80	100
601-650	625	3	5	15	75	103
651-700	675	10	6	60	360	116
701-750	725	3	7	21	147	117
751-800	775	1	8	8	64	120
801-850	825	3	9	27	243	120
851-900	875	0	10	0	0	120
901-950	925	0	11	0	0	120
951-1000	975	0	12	0	0	120
TOTALS		120		112	1424	1488

$$\bar{X} = X_a + \frac{\Sigma fx}{N} \times C = 375 + \frac{112}{120} \times 50 = 422 \text{ cycles}$$

$$\sigma = C\sqrt{\frac{\Sigma fx^2}{N}} = 50\sqrt{\frac{1424}{120}} = 173 \text{ cycles}$$

Table 18. Frequency Distribution, Cumulative Frequency and the Calculation of the Average and Standard Deviation for the Abrasion Resistance of Yarn B

Class Interval (cycles)	Mid Point	Frequency (f)	x	fx	fx^2	Cumulative Frequency
0-50	25	0	-9	0	0	0
51-100	75	1	-8	-8	64	1
101-150	125	10	-7	-70	490	11
151-200	175	14	-6	-84	504	25
201-250	225	8	-5	-40	200	33
251-300	275	8	-4	-32	128	41
301-350	325	8	-3	-24	72	49
351-400	375	15	-2	-30	60	64
401-450	425	17	-1	-17	17	81
451-500	475	9	0	0	0	90
501-550	525	6	1	6	6	96
551-600	575	2	2	4	8	98
601-650	625	5	3	15	45	103
651-700	675	7	4	28	112	110
701-750	725	1	5	5	25	111
751-800	775	3	6	18	108	114
801-850	825	2	7	14	98	116
851-900	875	2	8	16	128	118
901-950	925	1	9	9	81	119
951-1000	975	1	10	10	100	120
TOTALS		120		-180	2246	1500

$$\bar{X} = X_a + \frac{\sum fx}{N} \times C = 475 + \left(\frac{-180}{120}\right) \times 50 = 400 \text{ cycles}$$

$$\sigma = C\sqrt{\frac{\sum fx^2}{N}} = 50\sqrt{\frac{2246}{120}} = 216 \text{ cycles}$$

Table 19. Frequency Distribution, Cumulative Frequency and the Calculation of the Average and Standard Deviation for the Abrasion Resistance of Yarn C

Class Interval (cycles)	Mid Point	Frequency (f)	x	fx	fx^2	Cumulative Frequency
0-50	25	0	- 6	0	0	0
51-100	75	2	- 5	-10	50	2
101-150	125	2	- 4	- 8	32	4
151-200	175	9	- 3	-27	81	13
201-250	225	13	- 2	-26	52	26
251-300	275	8	- 1	- 8	8	34
301-350	325	28	0	0	0	62
351-400	375	19	1	19	19	81
401-450	425	14	2	28	56	95
451-500	475	9	3	27	81	104
501-550	525	6	4	24	96	110
551-600	575	5	5	25	125	115
601-650	625	1	6	6	36	116
651-700	675	1	7	7	49	117
701-750	725	3	8	24	192	120
751-800	775	0	9	0	0	120
801-850	825	0	10	0	0	120
851-900	875	0	11	0	0	120
901-950	925	0	12	0	0	120
951-1000	975	0	13	0	0	120
TOTALS		120		81	877	1599

$$\bar{X} = X_a + \frac{\Sigma fx}{N} \times C = 325 + \frac{81}{120} \times 50 = 359 \text{ cycles}$$

$$\sigma = C \sqrt{\frac{\Sigma fx^2}{N}} = 50 \sqrt{\frac{877}{120}} = 135 \text{ cycles}$$

Table 20. Frequency Distribution, Cumulative Frequency and the Calculation of the Average and Standard Deviation for the Abrasion Resistance of Yarn D

Class Interval (cycles)	Mid Point	Frequency (f)	x	fx	fx^2	Cumulative Frequency
0-50	25	0	-6	0	0	0
51-100	75	2	-5	-10	50	2
101-150	125	1	-4	-4	16	3
151-200	175	9	-3	-27	81	12
201-250	225	9	-2	-18	36	21
250-300	275	17	-1	-17	17	38
301-350	325	18	0	0	0	56
351-400	375	11	1	11	11	67
401-450	425	17	2	34	68	84
451-500	475	15	3	45	135	99
501-550	525	2	4	8	32	101
551-600	575	4	5	20	100	105
601-650	625	4	6	24	144	109
651-700	675	7	7	49	343	116
701-750	725	3	8	24	192	119
751-800	775	1	9	9	81	120
801-850	825	0	10	0	0	120
851-900	875	0	11	0	0	120
901-950	925	0	12	0	0	120
951-1000	975	0	13	0	0	120
TOTALS		120		148	1306	1532

$$\bar{X} = X_a + \frac{\Sigma fx}{N} \times C = 325 + \frac{148}{120} \times 50 = 387 \text{ cycles}$$

$$\sigma = C\sqrt{\frac{\Sigma fx^2}{N}} = 50\sqrt{\frac{1306}{120}} = 165 \text{ cycles}$$

Table 21. Frequency Distribution, Cumulative Frequency and the Calculation of the Average and Standard Deviation for the Abrasion Resistance of Yarn E

Class Interval	Mid Point	Frequency (f)	x	fx	fx^2	Cumulative Frequency
0-50	25	0	-9	0	0	0
51-100	75	0	-8	0	0	0
101-150	125	0	-7	0	0	0
151-200	175	11	-6	-66	396	11
201-250	225	4	-5	-20	100	15
251-300	275	15	-4	-60	240	30
301-350	325	16	-3	-48	144	46
351-400	375	17	-2	-34	68	63
401-450	425	15	-1	-15	15	78
451-500	475	18	0	0	0	96
501-550	525	6	1	6	6	102
551-600	575	6	2	12	24	108
601-650	625	5	3	15	30	113
651-700	675	3	4	12	48	116
701-750	725	3	5	15	75	119
751-800	775	0	6	6	36	119
801-850	825	1	7	7	49	120
851-900	875	0	8	0	0	120
901-950	925	0	9	0	0	120
951-1000	975	0	10	0	0	120
TOTALS		120		-170	1231	1496

$$\bar{X} = X_a + \frac{\sum fx}{N} \times C = 475 + \left(\frac{-170}{120}\right) \times 50 = 404 \text{ cycles}$$

$$\sigma = C\sqrt{\frac{\sum fx^2}{N}} = 50\sqrt{\frac{1231}{120}} = 158 \text{ cycles}$$

Table 22. Frequency Distribution, Cumulative Frequency and the Calculation of the Average and Standard Deviation for the Abrasion Resistance of Yarn F

Class Interval (cycles)	Mid Point	Frequency (f)	x	fx	fx^2	Cumulative Frequency
0-50	25	1	-5	-5	25	1
51-100	75	12	-4	-48	192	13
101-150	125	12	-3	-36	108	25
151-200	175	14	-2	-28	56	39
201-250	225	18	-1	-18	18	57
251-300	275	17	0	0	0	74
301-350	325	13	1	13	13	87
351-400	375	6	2	12	24	93
401-450	425	6	3	18	54	99
451-500	475	9	4	36	144	108
501-550	525	3	5	15	75	111
551-600	575	2	6	12	72	113
601-650	625	2	7	14	98	115
651-700	675	2	8	16	128	117
701-750	725	1	9	9	81	118
751-800	775	1	10	10	100	119
801-850	825	0	11	0	0	119
851-900	875	0	12	0	0	119
901-950	925	0	13	0	0	119
951-1000	975	1	14	14	196	120
TOTALS		120		34	1384	1766

$$\bar{X} = X_5 + \frac{\sum fx}{N} \times C = 275 + \frac{34}{120} \times 50 = 289 \text{ cycles}$$

$$\sigma = C \sqrt{\frac{\sum fx^2}{N}} = 50 \sqrt{\frac{1384}{120}} = 167 \text{ cycles}$$

Table 23. Frequency Distribution and the Calculation of the Average and Standard Deviation for the Tensile Strength of Yarn A

Class Interval (pounds)	Mid Point	Frequency (f)	(x)	(fx)	(fx^2)
.70-.80	.75	0	- 7	0	0
.81-.90	.85	0	- 6	0	0
.91-1.00	.95	0	- 5	0	0
1.01-1.10	1.05	1	- 4	- 4	16
1.11-1.20	1.15	2	3	- 6	18
1.21-1.30	1.25	18	- 2	-36	72
1.31-1.40	1.35	25	- 1	-25	25
1.41-1.50	1.45	24	0	0	0
1.51-1.60	1.55	27	1	27	27
1.61-1.70	1.65	16	2	32	64
1.71-1.80	1.75	7	3	21	63
TOTALS		120		9	285

$$\bar{X}_{TS} = X_a + \frac{\Sigma fx}{N} \times C = 1.45 + \frac{9}{120} \times 0.10 = 1.45 + .0075 = 1.46 \text{ lbs}$$

$$\sigma_{TS} = C \sqrt{\frac{\Sigma fx^2}{N}} = 0.10\sqrt{\frac{285}{120}} = 0.10 \sqrt{2.38} = 0.10 \times 1.51 = 0.151 \text{ lbs}$$

Table 24. Frequency Distribution and the Calculation of the Average and Standard Deviation for the Tensile Strength of Yarn B

Class Interval (pounds)	Mid Point	Frequency (f)	(x)	(fx)	(fx^2)
.70-.80	.75	1	-6	-6	36
.81-.90	.85	1	-5	-5	25
.91-1.00	.95	3	-4	-12	48
1.01-1.10	1.05	11	-3	-33	99
1.11-1.20	1.15	18	-2	-36	72
1.21-1.30	1.25	26	-1	-26	26
1.31-1.40	1.35	32	0	0	0
1.41-1.50	1.45	19	1	19	19
1.51-1.60	1.55	6	2	12	24
1.61-1.70	1.65	3	3	9	27
1.71-1.80	1.75	0	4	0	0
TOTALS		120		-88	376

$$\bar{X}_{TS} = X_a + \frac{\Sigma fx}{N} \times C = 1.35 + \left(\frac{-88}{120}\right) \times 0.10 = 1.35 - .07 = 1.28 \text{ lbs}$$

$$\sigma_{TS} = C \sqrt{\frac{\Sigma fx^2}{N}} = 0.10 \sqrt{\frac{376}{120}} = 0.10 \sqrt{3.13} = 0.10 \times 1.71 = 0.171 \text{ lbs}$$

Table 25. Frequency Distribution and the Calculation of the Average and Standard Deviation for the Tensile Strength of Yarn C

Class Interval (pounds)	Mid Point	Frequency (f)	(x)	(fx)	(fx^2)
.70-.80	.75	0	-6	0	0
.81-.90	.85	0	-5	0	0
.91-1.00	.95	3	-4	-12	48
1.01-1.10	1.05	5	-3	-15	45
1.11-1.20	1.15	13	-2	-26	52
1.21-1.30	1.25	18	-1	-18	18
1.31-1.40	1.35	31	0	0	0
1.41-1.50	1.45	20	1	20	20
1.51-1.60	1.55	21	2	42	84
1.61-1.70	1.65	8	3	24	72
1.71-1.80	1.75	1	4	4	16
TOTALS		120		19	355

$$\bar{X}_{TS} = X_a + \frac{\Sigma fx}{N} \times C = 1.35 + \frac{19}{120} \times 0.10 = 1.35 + 0.16 = 1.37 \text{ lbs}$$

$$\sigma_{TS} = C\sqrt{\frac{\Sigma fx^2}{N}} = 0.10\sqrt{\frac{355}{120}} = 0.10\sqrt{2.96} = 0.10 \times 1.72 = 0.172 \text{ lbs}$$

Table 26. Frequency Distribution and the Calculation of the Average and Standard Deviation for the Tensile Strength of Yarn D

Class Interval (pounds)	Mid Point	Frequency (f)	(x)	(fx)	(fx^2)
.70-.80	.75	1	- 5	- 5	25
.81-.90	.85	1	- 4	- 4	16
.91-1.00	.95	5	- 3	-15	45
1.01-1.10	1.05	12	- 2	-24	48
1.11-1.20	1.15	27	- 1	-27	27
1.21-1.30	1.25	32	0	0	0
1.31-1.40	1.35	27	1	27	27
1.41-1.50	1.45	10	2	20	40
1.51-1.60	1.55	5	3	15	45
1.61-1.70	1.65	0	4	0	0
1.71-1.80	1.75	0	5	0	0
TOTALS		120		-13	273

$$\bar{X}_{TS} = X_a + \frac{\Sigma fx}{N} \times C = 1.25 + \left(\frac{-13 \times .10}{120}\right) = 1.25 + \left(\frac{-1.3}{120}\right) = 1.25 - 0.01$$

$$\bar{X}_{TS} = 1.24 \text{ lbs}$$

$$\sigma_{TS} = C\sqrt{\frac{273}{N}} = 0.1 \sqrt{2.28} = 0.1 \times 1.51 = 0.151 \text{ lbs}$$

Table 27. Frequency Distribution and the Calculation of the Average and Standard Deviation for the Tensile Strength of Yarn E

Class Interval (pounds)	Mid Point	Frequency (f)	(x)	(fx)	(fx^2)
.70-.80	.75	0	- 4	0	0
.81-.90	.85	3	- 3	- 9	27
.91-1.00	.95	10	- 2	-20	40
1.01-1.10	1.05	13	- 1	-13	13
1.11-1.20	1.15	36	0	0	0
1.21-1.30	1.25	26	1	26	26
1.31-1.40	1.35	23	2	46	92
1.41-1.50	1.45	6	3	18	54
1.51-1.60	1.55	3	4	12	48
1.61-1.70	1.65	0	5	0	0
1.71-1.80	1.75	0	6	0	0
TOTALS		120		60	300

$$\bar{X}_{TS} = X_a + \frac{\Sigma fx}{N} \times C = 1.15 + \frac{60}{120} \times 0.10 = 1.15 + 0.05 = 1.20 \text{ lbs}$$

$$\sigma_{TS} = C\sqrt{\frac{\Sigma fx^2}{N}} = 0.10\sqrt{\frac{300}{120}} = 0.10 \times \sqrt{2.50} = 0.10 \times 1.51 = 0.151 \text{ lbs}$$

Table 28. Frequency Distribution and the Calculation of the Average and Standard Deviation for the Tensile Strength of Yarn F

Class Interval (pounds)	Mid Point	Frequency (f)	(x)	(fx)	(fx^2)
.70-.80	.75	3	- 4	-12	48
.81-.90	.85	6	- 3	-18	54
.91-1.00	.95	13	- 2	-26	52
1.01-1.10	1.05	23	- 1	-23	23
1.11-1.20	1.15	38	0	0	
1.21-1.30	1.25	16	1	16	16
1.31-1.40	1.35	12	2	24	48
1.41-1.50	1.45	5	3	15	45
1.51-1.60	1.55	1	4	4	16
1.61-1.70	1.65	3	5	15	75
1.71-1.80	1.75	0	6	0	0
TOTALS		120		-5	377

$$\bar{X}_{TS} = X_a + \frac{\Sigma fx}{N} \times C = 1.15 + \left(\frac{-5}{120}\right)0.10 = 1.15 - 0.004 = 1.15 \text{ lbs}$$

$$\sigma_{TS} = C\sqrt{\frac{\Sigma fx^2}{N}} = 0.10\sqrt{\frac{377}{120}} = 0.10\sqrt{3.14} = 0.10 \times 1.71 = 0.171 \text{ lbs}$$

Table 29. Frequency Distribution and the Calculation of the Average and Standard Deviation for the Elongation of Yarn A

Class Interval (Per Cent)	Mid Point	Frequency (f)	(x)	(fx)	(fx^2)
1.51-2.00	1.75	0	- 8	0	0
2.01-2.50	2.25	0	- 7	0	0
2.51-3.00	2.75	0	- 6	0	0
3.01-3.50	3.25	0	- 5	0	0
3.51-4.00	3.75	0	- 4	0	0
4.01-4.50	4.25	10	- 3	-30	90
4.51-5.00	4.75	18	- 2	-36	72
5.01-5.50	5.25	28	- 1	-28	28
5.51-6.00	5.75	37	0	0	0
6.01-6.50	6.25	19	1	19	19
6.51-7.00	6.75	7	2	14	28
7.01-7.50	7.25	1	3	3	9
TOTALS		120		-58	247

$$\bar{X}_E = X_a + \frac{\Sigma fx}{N} C = 5.75 + \left(\frac{-58 \times 0.5}{120}\right) = 5.75 - .24 = 5.51\%$$

$$\sigma_E = C\sqrt{\frac{\Sigma fx^2}{N}} = C\sqrt{\frac{247}{120}} = 0.5 \times \sqrt{2.06} = 1.44 \times 0.5 = 0.72\%$$

Table 30. Frequency Distribution and the Calculation of the Average and Standard Deviation for the Elongation of Yarn B

Class Interval (Per Cent)	Mid Point	Frequency (f)	(x)	(fx)	(fx^2)
1.51-2.00	1.75	0	- 6	0	0
2.01-2.50	2.25	0	- 5	0	0
2.51-3.00	2.75	1	- 4	- 4	16
3.01-3.50	3.25	2	- 3	- 6	18
3.51-4.00	3.75	16	- 2	-32	64
4.01-4.50	4.25	29	- 1	-29	29
4.51-5.00	4.75	31	0	0	0
5.01-5.50	5.25	29	1	29	29
5.51-6.00	5.75	8	2	16	32
6.01-6.50	6.25	3	3	9	27
6.51-7.00	6.75	0	4	0	0
7.01-7.50	7.25	1	5	5	25
TOTALS		120		-12	240

$$\bar{X}_E = X_a + \frac{\Sigma fx}{N} C = 4.75 + \left(\frac{-12 \times 0.5}{120}\right) = 4.75 - 0.005 = 4.75\%$$

$$\sigma_E = C\sqrt{\frac{\Sigma fx^2}{N}} = 0.5\sqrt{\frac{240}{120}} = 0.5\sqrt{2.00} = 0.5 \times 1.41 = 0.71\%$$

Table 31. Frequency Distribution and the Calculation of the Average and Standard Deviation for the Elongation of Yarn C

Class Interval (Per Cent)	Mid Point	Frequency (f)	(x)	(fx)	(fx^2)
1.51-2.00	1.75	0	- 4	0	0
2.01-2.50	2.25	2	- 3	- 6	18
2.50-3.00	2.75	3	- 2	- 6	12
3.01-3.50	3.25	16	- 1	-16	16
3.51-4.00	3.75	33	0	0	0
4.01-4.50	4.25	42	1	42	42
4.51-5.00	4.75	18	2	36	78
5.01-5.50	5.25	4	3	12	36
5.51-6.00	5.75	1	4	4	16
6.01-6.50	6.25	1	5	5	25
6.51-7.00	6.75	0	6	0	0
7.01-7.50	7.25	0	7	0	0
TOTALS		120		71	243

$$\bar{X}_E = X_a + \frac{\Sigma fx}{N} \times C = 3.75 + \frac{71 \times 0.5}{120} = 3.75 + 30 = 4.05\%$$

$$\sigma_E = C\sqrt{\frac{\Sigma fx^2}{N}} = 0.5\sqrt{\frac{243}{120}} = 0.5\sqrt{2.025} = 0.5 \times 1.42 = 0.71\%$$

Table 32. Frequency Distribution and the Calculation of the Average and Standard Deviation for the Elongation of Yarn D

Class Interval (Per Cent)	Mid Point	Frequency (f)	(x)	(fx)	(fx^2)
1.51-2.00	1.75	1	- 5	- 5	25
2.01-2.50	2.25	2	- 4	- 8	32
2.51-3.00	2.75	1	- 3	- 3	9
3.01-3.50	3.25	6	- 2	-12	24
3.51-4.00	3.75	24	- 1	-24	24
4.01-4.50	4.25	24	0	0	0
4.51-5.00	4.75	28	1	28	28
5.01-5.50	5.25	23	2	46	92
5.51-6.00	5.75	8	3	24	72
6.01-6.50	6.25	3	4	12	48
6.51-7.00	6.75	0	5	0	0
7.01-7.50	7.25	0	6	0	0
TOTALS		120		58	354

$$\bar{X}_E = X_a + \frac{\Sigma fx}{N} c = 4.25 + \frac{58 \times 0.5}{120} = 4.25 + 0.24 = 4.49\%$$

$$\sigma_E = c\sqrt{\frac{\Sigma fx^2}{N}} = 0.5\sqrt{\frac{354}{120}} = 0.5\sqrt{2.95} = 0.5 \times 1.71 = 0.85\%$$

Table 33. Frequency Distribution and the Calculation of the Average and Standard Deviation for the Elongation of Yarn E

Class Interval (Per Cent)	Mid Point	Frequency (f)	(x)	(fx)	(fx^2)
1.51-2.00	1.75	0	- 5	0	0
2.01-2.50	2.25	1	- 4	- 4	16
2.51-3.00	2.75	3	- 3	- 9	27
3.01-3.50	3.25	16	- 2	-32	64
3.51-4.00	3.75	20	- 1	-20	20
4.01-4.50	4.25	29	0	0	0
4.51-5.00	4.75	29	1	29	29
5.01-5.50	5.25	15	2	15	30
5.51-6.00	5.75	5	3	15	45
6.01-6.50	6.25	2	4	8	32
6.51-7.00	6.75	0	5	0	0
7.01-7.50	7.25	0	6	0	0
TOTALS		120		-2	263

$$\bar{X}_E = X_a + \frac{\Sigma fx}{N} c = 4.25 + \left(\frac{-2 \times .05}{120}\right) = 4.25 - .01 = 4.24\%$$

$$\sigma_E = c\sqrt{\frac{\Sigma fx^2}{N}} = 0.5\sqrt{\frac{263}{120}} = 0.5\sqrt{2.19} = 0.5 \times 1.48 = 0.74\%$$

Table 34. Frequency Distribution and the Calculation of the Average and Standard Deviation for the Elongation of Yarn F

Class Interval (Per Cent)	Mid Point	Frequency (f)	(x)	(fx)	(fx^2)
1.51-2.00	1.75	0	- 6	0	0
2.01-2.50	2.25	0	- 5	0	0
2.51-3.00	2.75	3	- 4	-12	48
3.01-3.50	3.25	10	- 3	-30	90
3.51-4.00	3.75	24	- 2	-48	96
4.01-4.50	4.25	26	- 1	-26	26
4.51-5.00	4.75	34	0	0	0
5.01-5.50	5.25	15	1	15	15
5.51-6.00	5.75	5	2	10	20
6.01-6.50	6.25	3	3	9	27
6.51-7.00	6.75	0	4	0	0
7.01-7.50	7.25	0	5	0	0
TOTALS		120		-82	322

$$\bar{X}_E = X_a + \frac{\Sigma fx}{N} c = 4.75 + \left(\frac{-82 \times 0.5}{120}\right) = 4.75 - .34 = 4.41\%$$

$$\sigma_E = c\sqrt{\frac{\Sigma fx^2}{N}} = 0.5\sqrt{\frac{322}{120}} = 0.5\sqrt{2.68} = 0.5 \times 1.64 = 0.82\%$$

Table 35. Cumulative Frequencies, in Per Cent, for the Abrasion Resistance of Yarn A (Cycles)

Class Interval (cycles)	Mid Point	Run 1	Plus Run 2	Plus Run 3	Plus Run 4	Plus Run 5	Plus Run 6
0-50	25	0.00	0.00	0.00	0.00	0.00	0.00
51-100	75	0.00	0.00	0.00	0.00	0.00	0.00
101-150	125	0.00	0.00	1.66	1.25	1.00	0.83
151-200	175	10.00	10.00	9.99	8.75	8.00	8.33
201-250	225	25.00	22.50	21.66	17.50	16.00	16.66
251-300	275	30.00	35.00	31.66	26.25	24.00	25.00
301-350	325	40.00	45.00	43.33	38.75	37.00	36.66
351-400	375	55.00	62.50	63.33	55.00	53.00	50.00
401-450	425	60.00	75.00	73.33	63.75	61.00	59.16
451-500	475	80.00	87.50	86.66	76.25	74.00	73.33
501-550	525	90.00	95.00	93.33	82.50	80.00	79.16
551-600	575	90.00	95.00	93.33	85.00	84.00	83.33
601-650	625	90.00	95.00	96.66	87.50	86.00	85.83
651-700	675	100.00	100.00	100.00	97.50	96.00	94.16
701-750	725	100.00	100.00	100.00	98.75	98.00	96.66
751-800	775	100.00	100.00	100.00	98.75	98.00	97.49
801-850	825	100.00	100.00	100.00	100.00	100.00	100.00
851-900	875	100.00	100.00	100.00	100.00	100.00	100.00
901-950	925	100.00	100.00	100.00	100.00	100.00	100.00
951-1,000	975	100.00	100.00	100.00	100.00	100.00	100.00

Table 36. Cumulative Frequencies, in Per Cent, for the Abrasion Resistance of Yarn B (Cycles)

Class Interval (cycles)	Mid Point	Run 1	Plus Run 2	Plus Run 3	Plus Run 4	Plus Run 5	Plus Run 6
0-50	25	0.00	0.00	0.00	0.00	0.00	0.00
51-100	75	5.00	2.50	1.66	1.25	1.00	0.83
101-150	125	10.00	7.50	8.33	8.75	8.00	9.17
151-200	175	20.00	17.50	14.99	18.75	18.00	20.83
201-250	225	20.00	22.50	19.99	23.75	25.00	27.49
251-300	275	35.00	32.50	28.33	31.25	33.00	34.16
301-350	325	35.00	35.00	31.66	36.25	39.00	40.83
351-400	375	40.00	42.50	44.99	50.00	52.00	53.33
401-450	425	50.00	60.00	59.99	65.00	67.00	67.49
451-500	475	60.00	70.00	69.99	72.50	74.00	74.99
501-550	525	60.00	72.50	74.99	77.50	80.00	79.99
551-600	575	65.00	75.00	76.66	78.75	82.00	81.66
601-650	625	65.00	75.00	81.66	82.50	86.00	85.83
651-700	675	75.00	82.50	86.66	87.50	90.00	91.66
701-750	725	80.00	85.00	88.33	88.75	91.00	92.49
751-800	775	80.00	90.00	93.33	92.50	94.00	94.99
801-850	825	85.00	92.50	94.99	95.00	96.00	96.66
851-900	875	95.00	97.50	98.33	97.50	98.00	98.33
901-950	925	100.00	100.00	100.00	98.75	99.00	99.16
951-1,000	975	100.00	100.00	100.00	100.00	100.00	100.00

Table 37. Cumulative Frequencies, in Per Cent, for the Abrasion Resistance of Yarn C (Cycles)

Class Interval (cycles)	Mid Point	Run 1	Plus Run 2	Plus Run 3	Plus Run 4	Plus Run 5	Plus Run 6
0-50	25	0.00	0.00	0.00	0.00	0.00	0.00
51-100	75	5.00	5.00	3.33	2.50	2.00	1.66
101-150	125	5.00	7.50	4.99	3.75	3.00	3.33
151-200	175	20.00	17.50	14.99	13.75	11.00	10.83
201-250	225	25.00	20.00	21.66	27.50	22.00	21.66
251-300	275	25.00	27.50	33.33	36.25	29.00	28.33
301-350	325	45.00	50.00	53.33	58.75	49.00	51.66
351-400	375	70.00	70.00	71.66	75.00	66.00	67.49
401-450	425	90.00	85.00	83.33	85.00	77.00	79.16
451-500	475	100.00	92.50	88.33	91.25	86.00	86.66
501-550	525	100.00	97.50	94.99	96.25	91.00	91.66
551-600	575	100.00	97.50	94.99	96.25	95.00	95.83
601-650	625	100.00	97.50	96.66	97.50	96.00	96.66
651-700	675	100.00	97.50	96.66	97.50	97.00	97.49
701-750	725	100.00	100.00	100.00	100.00	100.00	100.00
751-800	775	100.00	100.00	100.00	100.00	100.00	100.00
801-850	825	100.00	100.00	100.00	100.00	100.00	100.00
851-900	875	100.00	100.00	100.00	100.00	100.00	100.00
901-950	925	100.00	100.00	100.00	100.00	100.00	100.00
951-1,000	975	100.00	100.00	100.00	100.00	100.00	100.00

Table 38. Cumulative Frequencies, in Per Cent, for the Abrasion Resistance of Yarn D (Cycles)

Class Interval (cycles)	Mid Point	Run 1	Plus Run 2	Plus Run 3	Plus Run 4	Plus Run 5	Plus Run 6
0-50	25	0.00	0.00	0.00	0.00	0.00	0.00
51-100	75	5.00	2.50	1.66	2.50	2.00	1.66
101-150	125	5.00	2.50	1.66	3.75	3.00	2.49
151-200	175	5.00	12.50	8.33	11.25	10.00	9.99
201-250	225	5.00	15.00	11.66	17.50	18.00	17.49
251-300	275	30.00	32.50	29.99	32.50	32.00	31.66
301-350	325	40.00	45.00	46.66	48.75	47.00	46.66
351-400	375	50.00	52.50	53.33	56.25	56.00	55.83
401-450	425	80.00	72.50	69.99	72.50	69.00	69.99
451-500	475	85.00	82.50	83.33	83.75	81.00	82.49
501-550	525	90.00	85.00	84.99	86.25	83.00	84.16
551-600	575	95.00	90.00	88.33	88.75	86.00	87.49
601-650	625	95.00	90.00	88.33	88.75	90.00	90.83
651-700	675	100.00	100.00	98.33	96.25	96.00	96.66
701-750	725	100.00	100.00	100.00	100.00	99.00	99.16
751-800	725	100.00	100.00	100.00	100.00	100.00	100.00
801-850	825	100.00	100.00	100.00	100.00	100.00	100.00
851-900	875	100.00	100.00	100.00	100.00	100.00	100.00
901-950	925	100.00	100.00	100.00	100.00	100.00	100.00
951-1,000	975	100.00	100.00	100.00	100.00	100.00	100.00

Table 39. Cumulative Frequencies, in Per Cent, for the Abrasion Resistance of Yarn E (Cycles)

Class Interval (cycles)	Mid Point	Run 1	Plus Run 2	Plus Run 3	Plus Run 4	Plus Run 5	Plus Run 6
0-50	25	0.00	0.00	0.00	0.00	0.00	0.00
51-100	75	0.00	0.00	0.00	0.00	0.00	0.00
101-150	125	0.00	0.00	0.00	0.00	0.00	0.00
151-200	175	10.00	10.00	9.99	10.00	9.00	9.16
201-250	225	15.00	15.00	13.33	13.75	12.00	12.49
251-300	275	15.00	20.00	23.33	26.25	25.00	24.99
301-350	325	45.00	42.50	38.33	40.00	38.00	38.33
351-400	375	50.00	55.00	53.33	52.50	51.00	52.49
401-450	425	65.00	70.00	66.66	67.50	65.00	64.99
451-500	475	75.00	80.00	78.33	80.00	80.00	79.99
501-550	525	90.00	90.00	84.99	86.25	85.00	84.99
551-600	575	90.00	92.50	93.33	93.75	91.00	89.99
601-650	625	95.00	97.50	96.66	97.50	95.00	94.16
651-700	675	100.00	100.00	100.00	100.00	97.00	96.66
701-750	725	100.00	100.00	100.00	100.00	99.00	99.16
751-800	775	100.00	100.00	100.00	100.00	99.00	99.16
801-850	825	100.00	100.00	100.00	100.00	100.00	100.00
851-900	875	100.00	100.00	100.00	100.00	100.00	100.00
901-950	925	100.00	100.00	100.00	100.00	100.00	100.00
951-1,000	975	100.00	100.00	100.00	100.00	100.00	100.00

Table 40. Cumulative Frequencies, in Per Cent, for the Abrasion Resistance of Yarn F (Cycles)

Class Interval (cycles)	Mid Point	Run 1	Plus Run 2	Plus Run 3	Plus Run 4	Plus Run 5	Plus Run 6
0-50	25	0.00	0.00	0.00	0.00	1.00	0.83
51-100	75	5.00	7.50	13.33	11.25	11.00	10.83
101-150	125	5.00	10.00	21.66	18.75	20.00	20.83
151-200	175	10.00	22.50	34.99	31.25	32.00	32.49
201-250	225	25.00	35.00	46.66	45.00	46.00	47.49
251-300	275	50.00	50.00	59.99	58.75	60.00	61.66
301-350	325	65.00	65.00	69.99	70.00	70.00	72.49
351-400	375	65.00	72.50	74.99	75.00	75.00	77.49
401-450	425	70.00	77.50	78.33	78.75	81.00	82.49
451-500	475	90.00	90.00	88.33	87.50	89.00	89.99
501-550	525	90.00	92.50	91.66	91.25	92.00	92.49
551-600	575	95.00	95.00	93.33	92.50	94.00	94.16
601-650	625	95.00	95.00	93.33	95.00	96.00	95.83
651-700	675	95.00	95.00	94.99	96.25	97.00	97.49
701-750	725	100.00	97.50	96.66	97.50	98.00	98.33
751-800	775	100.00	100.00	98.33	98.75	99.00	99.16
801-850	825	100.00	100.00	98.33	98.75	99.00	99.16
851-900	875	100.00	100.00	98.33	98.75	99.00	99.16
901-950	925	100.00	100.00	98.33	98.75	99.00	99.16
951-1,000	975	100.00	100.00	100.00	100.00	100.00	100.00

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